GENETIC AND PHYSIOLOGICAL ASPECTS OF RESISTANCE TO HYPOTHERMIA IN RELATION TO NEONATAL LAMB SURVIVAL

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FIRST SIGHT

Lambs that learn to walk in snow

When their bleating clouds the air

Meet a vast unwelcome, know

Nothing but a sunless glare.

Newly stumbling to and fro

All they find, outside the fold,

Is a wretched width of cold.

As they wait beside the ewe,

Her fleeces wetly caked, there lies

Hidden round them, waiting too,

Earth's immeasurable surprise.

They could not grasp it if they knew,

What so soon will wake and grow

Utterly unlike the snow.

Philip Larkin (b.1922)

CONTENTS

ABSTRACT

Every year many thousands of newborn lambs die of cold exposure. This thesis is concerned with some of the physiological and genetic factors involved in the resistance of neonatal lambs of ten different breeds to hypothermia with particular reference to their heat production capabilities.

The project was a development of preliminary work carried out at the Animal Breeding Research Organisation, Edinburgh during the year immediately preceding this study. An attempt was made to reproduce in the laboratory, a standard cold stress comparable to that experienced by the newborn lamb born into cold, wet and windy conditions. A suitable test was evolved using water as the cooling medium to reduce body temperature and measuring heat production (in the form of oxygen consumption) using an indirect open-circuit calorimeter.

265 lambs of ten different breeds were tested. Significant breed differences were found for resistance to body cooling and base metabolic rate. Peak metabolic rate was significantly affected by weight.

The results of the experimentation (1976-1979) give an insight into the variation existing, both within and between breeds, in the traits likely to be useful in the selection of individuals and breeds most suited to survive severe environmental conditions during the neonatal period.

An attempt was made to separate the effects of factors such as

weight, skin thickness, age, sex and litter size.

In particular, observations during cooling tests indicate the possible importance of tissue insulation, recorded in the form of skin thickness, in aiding the neonate to maintain body temperature in a cooling environment where fleece insulation is low.

It was thought that the insulative properties of the birthcoat were unlikely to be expressed under waterbath conditions and no significant effects of birthcoat were found despite there being significant breed variation in this trait. To demonstrate birthcoat effects a wind tunnel procedure was used with artificial wind and rain providing a cold stress. Use of this equipment allowed separation of the effects of birthcoat extremes within the Welsh Mountain breed.

The effect of fasting lambs from birth (4hrs) and pre-partum cold exposure of the dam were investigated for effects on the newborn's metabolic response to cold and cold resistance capabilities in the Scottish Blackface breed. The fasted lambs showed enhanced cold resistance possibly as a result of fat metabolism being initiated prior to the applied cold stress. Cold exposure of pre-partum ewes increased gestation length and the birth weight of their lambs. Base metabolic rate was lower for fasted lambs and peak metabolic rate enhanced in lambs from cold stressed ewes.

The contribution of non-shivering thermogenesis was investigated and emphasis placed on fat metabolism in early post natal life when brown adipose tissue may be particularly relevant in cold thermogenesis. Metabolic responses to injected noradrenaline were investigated and a comparison made between maximum metabolic response to cold and catecholamine stimulation in the Cheviot breed.

Some methods of rewarming were also studied with passive techniques showing possible field application.

The possibilities for selection of more cold resistant types of sheep are discussed.

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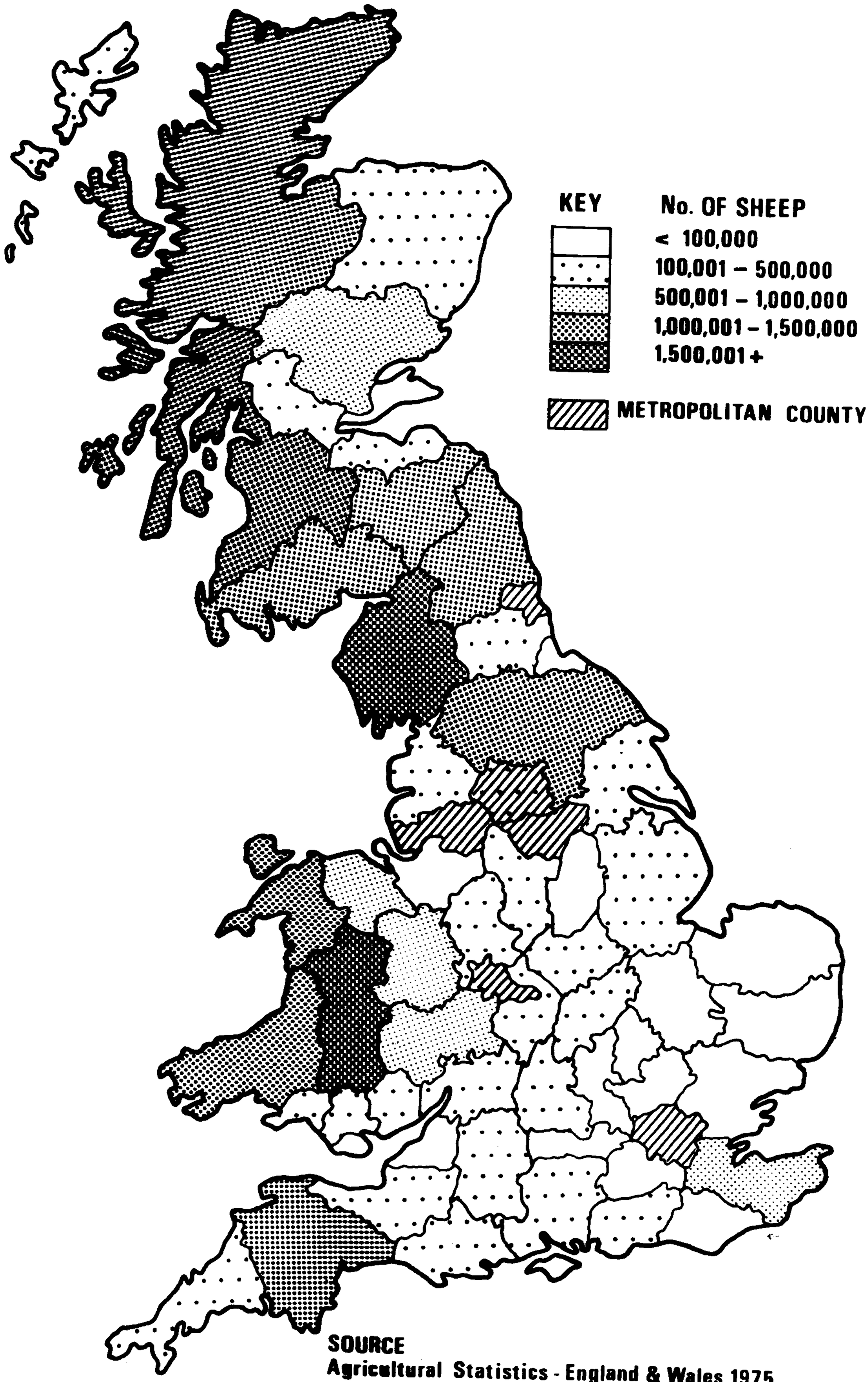
* for abbreviations see glossary

INTRODUCTION

Sheep are the most numerous grazing animals in the United Kingdom. The Ministry of Agriculture, Fisheries and Food's 1978 June census returned thirteen and a half million cattle compared with twenty nine and a half million sheep (HMSO, 1980). The distribution of sheep throughout the United Kingdom is more closely related to natural environmental conditions than for other livestock. Sixty two percent of all breeding ewes are found in the "hills and uplands" of Britain (MLC,1978). This distribution reflects the ability of sheep to utilize upland environments (see Fig 1) where other enterprises would be less productive or not viable, and also their inability to compete economically with other enterprises in lowland situations. The fact that the majority of sheep are found in upland areas does not imply the suitability of these areas for exploiting their full potential. Sheep are able to withstand low temperatures and high rainfall, but under such conditions they suffer production restraints (Table 1).

Traditionally hill sheep farms have low stocking rates with little nutritional supplement to grazing. Output is low with average weaning percentages in the range sixty to one hundred. However, sheep of traditional upland breeds are capable of increased productivity given correct management relative to environmental limitations (HFRO, 1979; Hamilton, 1978).Many technical advances have been advocated to raise sheep productivity, often aimed at increasing the number of lambs reared per ewe per year (Land,1978; HFRO,1979). One possible area for improvement, equally applicable to

FIG. 1. **DISTRIBUTION OF SHEEP BY REGION TAKEN FROM M.A.F.F. JUNE CENSUS 1975.**



SOURCE
Agricultural Statistics - England & Wales 1975
HMSO 1977
Scotland 1977
HMSO Edinburgh

FIG.1A. SIMPLIFIED RELIEF MAP- SCOTLAND, ENGLAND AND WALES

SOURCE
Collins Essential Atlas 1975

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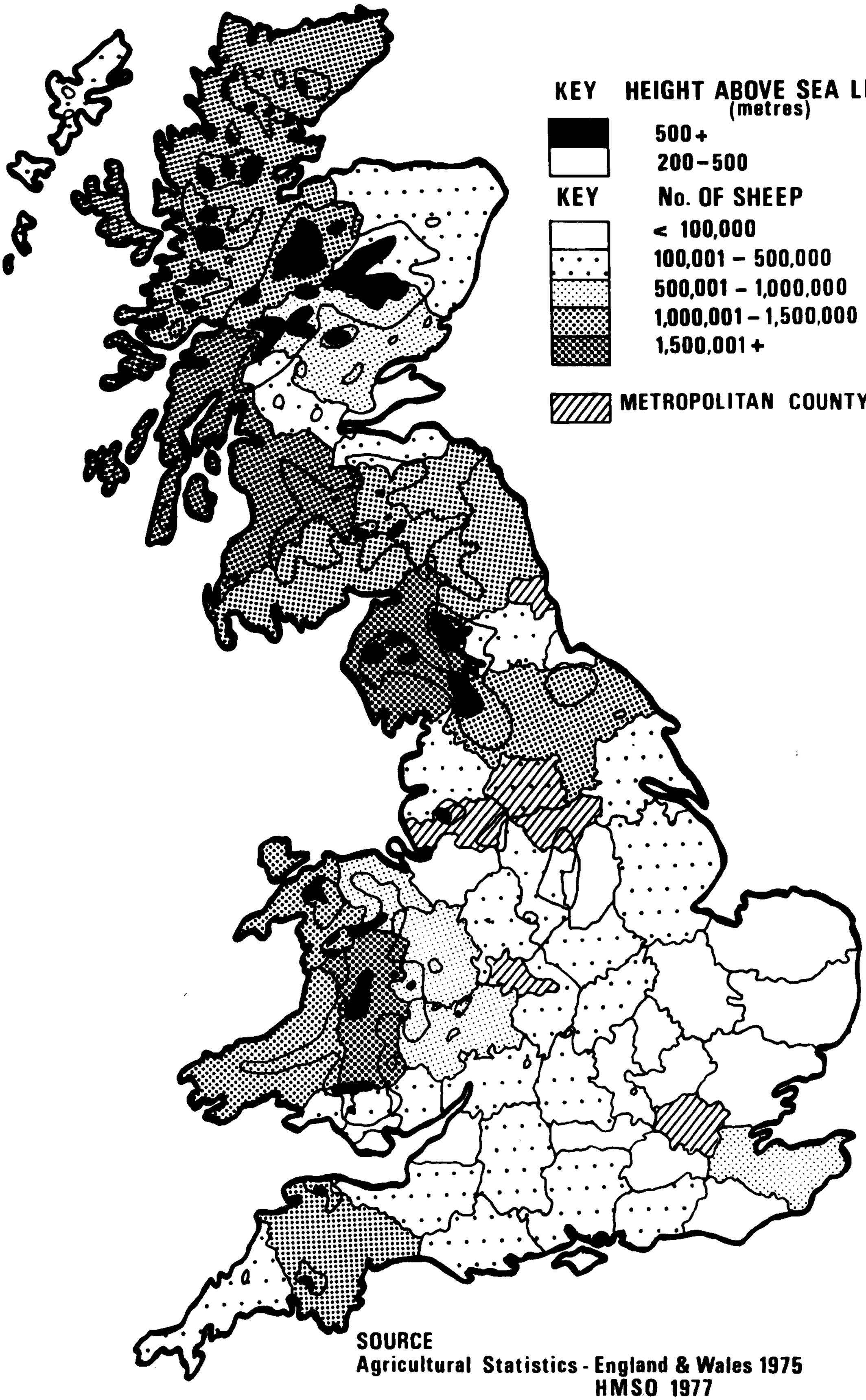

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traditional and more recently introduced systems, is to reduce the high incidence of neonatal lamb mortality.

Several estimates of the economic importance of lamb mortality have been made (MLC, 1978; Barton and Blyth, 1977; Purvis, Ostler, Starr, Baxter, Bishop, James, Dunn, Ould and McClintock, 1979; Howe, 1976).

TABLE 1 SUMMARY OF MLC RECORDED FLOCK PERFORMANCE DATA: LOWLAND AND UPLAND FLOCKS 1972-77

FLOCK TYPE	EWE DEATHS BEFORE LAMBING PER 100 EWES PUT TO RAM	TOTAL LAMBS BORN PER 100 EWES PUT TO RAM	LIVE LAMBS BORN PER EWE LAMBED	NUMBER OF LAMBS REARED PER 100 EWES PUT TO RAM
LOWLAND	2.0	163	1.66	140
UPLAND	2.2	137	1.38	119

Adapted from MLC (1978)

LITERATURE REVIEW

1.MORTALITY SURVEYS

Lamb mortality surveys have been widely documented from sources both within the United Kingdom and throughout the World (Tables 2; 2(i)). Data are often obscured for comparison purposes by failure of reporters to state if the neonatal mortality figures quoted include a figure representing stillbirths. The levels of pre-weaning mortality (including stillbirths) illustrated in the tables range from 6.6 to 18.8 percent with an average of approximately 12 percent. The problem appears to be world wide, occurring in many different climatic regions and in both upland and lowland flocks. Levels of mortality recorded in surveys may well underestimate the problem since in many cases it is only the farms with better management practices (Juma et al, 1973) that are likely to keep records and many of the surveys quoted throughout the literature refer to data collected from experimental flocks. Mortality on extensive hill farms is especially difficult to quantify.

Column 3 in Tables 2 and 2(i) illustrates the importance of the perinatal period as the time when most pre-weaning deaths are concentrated. About 30 per cent of total pre-weaning deaths may be classified as stillbirths (see Section 2) with another 30 percent occurring in live born lambs before they reach one week of age. Thus it is the immediate post-partum period where most influence can be exerted to reduce the mortality of live born lambs (Macleod, 1979; MLC, 1978).

TABLE 2 SUMMARY OF LAMB PRE-WEANING MORTALITY SURVEY DATA COMMERCIAL AND EXPERIMENTAL FLOCKS (BRITISH ISLES)

TOTAL NUMBER OF LAMBS IN SURVEY	STILLBIRTHS AS A PERCENTAGE OF TOTAL DEATHS	NEONATAL DEATHS 0 - 72HRS. AS A PERCENTAGE OF TOTAL DEATHS. INCLUDES STILL-BIRTHS	PERCENTAGE TOTAL DEATHS BIRTH TO WEANING. INCLUDES STILL-BIRTHS	YEARS OF SURVEY	COUNTRY	FLOCK DETAILS	BREEDS	SOURCE
1306		50.9	17.5	1979	Scotland	ABRO Hill Farm Stanhope, Peebles	Scottish Blackface Mostly pedigree	Stanhope Farm Records
1219	16.2	44.3(24hrs)	13.8	1976-79	Scotland	ABRO Dryden Farm (some born inside). Includes experimental animals.	Pure Breeds Scottish Blackface 307 Border Leicester 77 Boreray Blackface 35 Cheviot 105 Finnish Landrace 165 Tasmanian Merino 104 Oxford Down 50 Soay 127 Southdown 68 Welsh Mountain 181	Dryden Farm Records. See Appendix 1 for detailed breakdown of mortalities
1688	35.3		11.9	1976-77	England	Lowland Flock Berkshire	4 Cross Breeds	Purvis. Ostler, Starr, Baxter, Bishop, James, Dunne, Lynne, Ould and McClintock (1979)
1164		56.5(24hrs)	10.8 (2 weeks)	1963-65	Eire	University Flock Lowland	Suffolk Galway Cheviot Blackface Suffolk X	Gordon (1967)
15.522	18.2	88.2(10 days)	14.2	1974-76	Scotland	Caithness 10 Commercial Farms	Cheviot	Johnson (1978)
2426			12.1	1953-57	Wales	Merioneth	Welsh Mountain	Purser and Young (1959)
2266	38.4	77.8	13.3	1971-72	England	Northamptonshire Lowland. MLC data	Welsh Half Breed Scottish Half Breed Suffolk X Scottish Half Breed	Saunders (1975)
818			16.7	1979	Scotland	Commercial Farm	Cheviot X Blue Leicester Mule X Dorset	Barlow (1979)

TABLE 2 (i) SUMMARY OF LAMB PRE-WEANING MORTALITY SURVEY DATA COMMERCIAL AND EXPERIMENTAL FLOCKS (THE WORLD)

TOTAL NUMBER OF LAMBS IN SURVEY	STILLBIRTHS AS A PERCENTAGE OF TOTAL DEATHS.	NEONATAL DEATHS 0 - 72HRS. AS A PERCENTAGE OF TOTAL DEATHS INCLUDES STILL-BIRTHS	PERCENTAGE TOTAL DEATHS BIRTH TO WEANING. INCLUDES STILL-BIRTHS	YEARS OF SURVEY	COUNTRY	FLOCK DETAILS	BREEDS	SOURCE
4067	18.6		18.8	1921-57	USA	University of Illinois	Hampshire Southdown Shropshire Rambouillets	Vetter, Norton, and Garrigus (1960)
421	49.0		12.1	1964-66	Australia	CSIRO 3 Field Stations Victoria	Merino	Alexander, McCance and Watson (1955)
6121	30.0		14.2	1964-66	Australia	5 Research Farms	Merino Corriedale and Cross	Croker (1968)
7727	10.3		17.8	1959-67	New Zealand	Hill Flocks	Romney Border Leicester Cross Romney	Hight and Jury (1969)
673	17.5		9.3	1957-60	Egypt	Sakha and Gimmeza Experimental Farm	Oasimi	Labban, Radwan and El-Kady (1966)
5451	45.8	82.7(10 days)	13.4 (30 days)	12 years	Italy	Experimental Farm	7 Pure Breeds	Fredella (1974)
2957		30.9(15 days)	8.1	1967-71	Iraq	Experimental Station	Awassi	Juma, Eliya, Al-Rawi and Abumaaly (1974)
1102	32.9	68.0(24hrs)	9.2	1 year	Sweden	8 Flocks	Oxford Down Swedish Landrace Shropshire	Gunnarsson, Jacobsen and Mollerberg (1970)
5007	21.1	50.0+ (5 days)	7.0	1959-64	France	Commercial Flocks	Arles Merino	Prud'hon, Denoy and Desvignes (1968)

2.CAUSES OF DEATH

Much of the data recorded in surveys of causes of pre-weaning lamb deaths is very subjective and is not founded in actual post-mortem evidence. In many cases deaths recorded in the absence of post-mortem as "stillbirths"could be more accurately classified as neonatal death or late abortions, as only after inspection of the lung tissue, could death be said to have occurred prior to the birth process. Post-mortems recording a single cause of death can be misleading. In many cases weakness resulting from such varied causes as poor nutrition, difficult birth or extreme environmental conditions could result ultimately in death as a consequence of lowering disease resistance or from hypothermia and/or starvation. In such cases the predisposing factors are just as important as the terminal cause of death. Table 3 gives examples of cause of death surveys and illustrates the importance of starvation and inter-related hypothermia. This relationship is often termed the "Starvation -Exposure Complex" (Fig 2) and it's importance as a major cause of pre-weaning death (30 - 35 percent) has often been discussed in the literature (Slee, 1977; McDonald, 1962; Speedy et al 1975; Johnson, 1975; Huston and Maddox, 1974).

Post-mortem features of uncomplicated exposure and starvation in naturally occurring perinatal lamb mortality are described by McFarlane (1955, 1965). Further investigation carried out with Merino lambs in New Zealand (Haughey, 1973) has linked the post mortem features to allow determination of perinatal lamb losses attributable to the effects of starvation and cold exposure combined. The incidence of disease accounts for only a relatively small proportion of pre-weaning deaths (Bannatyne, 1975; Saunders, 1975)

TABLE 3 SUMMARY OF SOME SURVEYS OF CAUSES OF PRE-WEANING LAMB MORTALITY (PERCENTAGES OF DEATHS ATTRIBUTABLE TO EACH CAUSE

ABORTION AND STILL BIRTHS	DIFFICULT LAMBING PLACENTAL SMOTHERING	DISEASE/ ENTERIC DISORDER	STARVATION/ EXPOSURE	MISADVEN-TURE AND PREDATORS	DEFORMITY	CAUSE NOT ESTABLI-SHED	NUMBER OF LAMB DEATHS IN SURVEY	BREED(S)	SOURCE
30 - 40		15 - 20	20 - 30	5 - 10	5 - 10	-	-	Various	MLC(1978)
18.0	12.0	18.8	25.2	9.0	8.3	8.3	167	As Table 2	Dryden Farm Records
30.5		15.8	35.8	7.4	3.2	7.4	95 (14 days)	Greyface Scottish Halfbreed	Speedy, Linklater Mackenzie MacMillan& Blance(1975)
26.4	20.5	13.3	38.5	-	1.3	-	1956 (10 days)	North Country Cheviots	Johnston (1978)
37.4		22.2	30.8	5.6	-	4.0	198	4 Cross Breeds	Purvis et al (1979)
10.3	16.0	11.6	41.7	-	-	20.4	814	Romney Border Leicester X Romney	Hight and Jury (1969)

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even in fairly intensively stocked situations as at Dryden Farm where during 1976-1979 less than 15 percent of pre-weaning deaths showed evidence of any disease. Specific diseases which may cause problems are listed by Donald (1975). Other individual causes of death may be important in specific flock situations. Fogarty (1971) records 80 percent of perinatal deaths as a result of the effects of dystocia while Moule (1952) reports poor mothering and predators as the most important cause of mortality. Most surveys provide little information on the contribution of cold alone to pre-weaning deaths.

Obst and Day (1968) illustrate the dramatic effects of weather with 91.1 percent of newborn Merino lambs dying in winds of 15-35 miles per hour coupled with rainfall of between 5.3 and 26mm per day. Burroughs (1978) documenting the severe winter of 1947 in Britain states that 20 percent of the sheep population died, a situation from which full recovery took some five years.

Levels of mortality and causes of death for ABRO's Dryden Farm are shown in Tables A and B of Appendix 1.

3.FACTORS INFLUENCING SURVIVAL IN THE COLD

The "Starvation-Exposure" syndrome (Fig 2) is characterized in one extreme by relatively sudden death from acute hypothermia and in the other by cold implicated starvation of weak or deserted lambs. Factors predisposing death from either extreme may be very different and treatment of lambs in the field in inclement weather apparently suffering from hypothermia would be different in each case, the animal beyond points A on the diagram (Fig 2) will require sustenance in addition to warmth , whereas prior to point A where the lamb is merely overcome by extremes of the environment full recovery can be

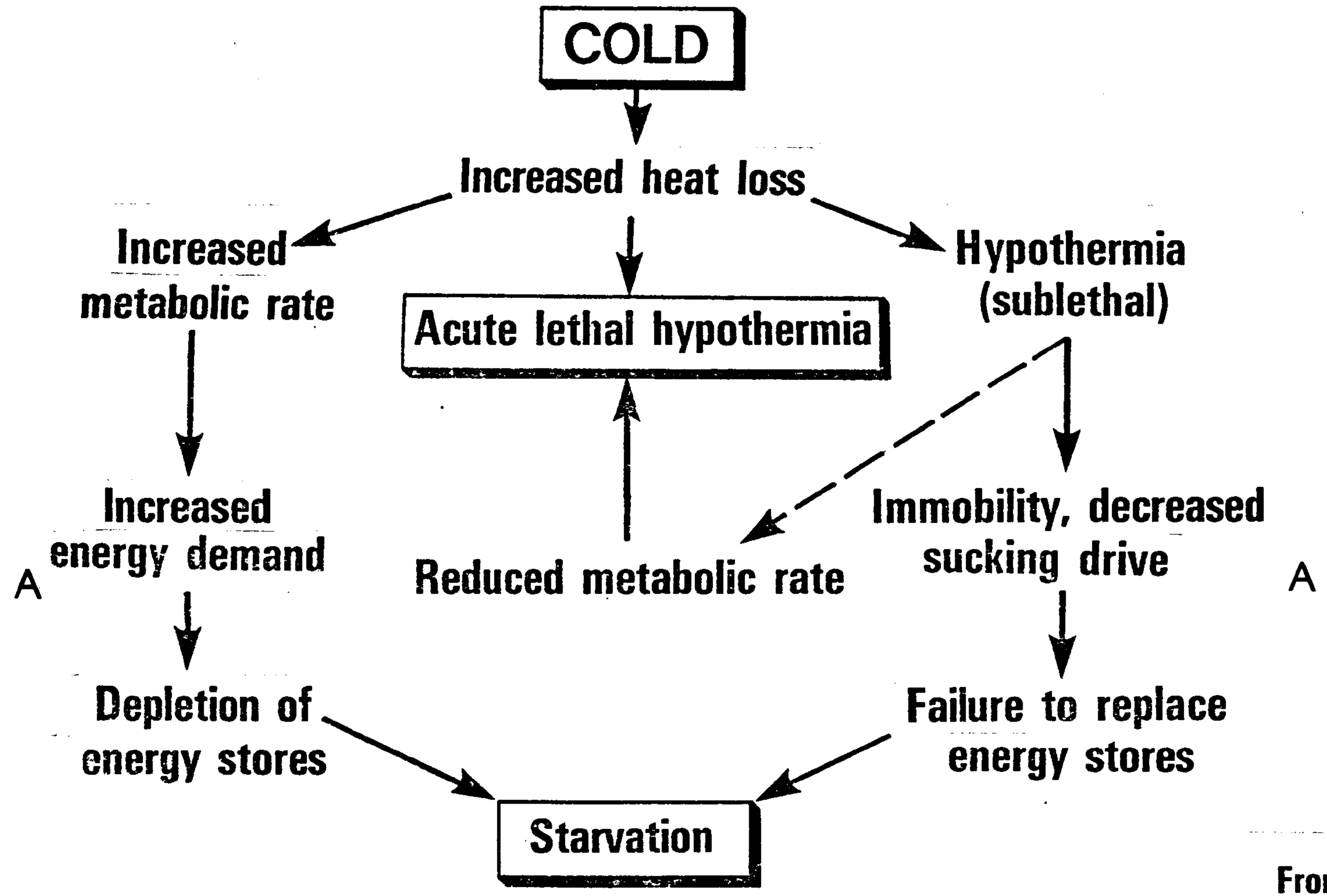


Fig. 2 Interaction of factors causing death or debility of neonatal lambs as a result of hypothermia or starvation.

attained with the supply of exogenous heat. The latter animal is often found "normal" at post-mortem with food in its stomach.

The newborn lamb, especially in the case of hill breeds, is usually born into an environment where the temperature is well below its body temperature. During the immediate post-partum period when the neonate is wet and relatively immobile it is particularly susceptible to the cooling powers of the environment. Sykes, Griffiths and Slee (1976) show a scatter diagram of body temperature relative to environmental conditions for newborn lambs of six breeds.

The newborn lamb is a vigorous homeotherm at birth (Mount, 1979); and as such can respond to cold stimulus by increasing its heat production and can reinforce its insulative properties by vaso-constriction.

The factors influencing survival and resistance to cold can be discussed in the following four categories:- physical, behavioural, genetic and physiological.

(A) PHYSICAL FACTORS.

(i)Birth Weight and Litter Size. Birth weight has been identified in many studies as exerting the biggest single influence on survival to weaning (Fredella, 1974; Malik and Acharya, 1972). Wiener and Hayter (1975) recorded a correlation of 0.1($p<0.001$) between birth weight and lamb survival to weaning within litter size groups for three hill breeds. Maximum survival rate for many studies is found for lambs within a specific weight range which is generally centred around the breed mean (Mullaney, 1969; Ragab, Asher and Kadi, 1954; Purser and Young, 1959). McMeriman and Young (1968) report more than 90 percent of lambs weighing less than 1.1 kilos at

birth dying during the neonatal period. Where available data includes a large spread of birth weights survival can be impaired at both ends of the weight spectrum (Alexander et al, 1955; Gunn and Robinson, 1963; Lax and Brown, 1968; Hight and Jury, 1969). Body size plays an important part in environmental heat exchange. Sensible (Non-evaporative) heat loss, especially radiation and convection, is the main channel for heat exchange for homeotherms in cold environments. The higher surface area to body mass ratio in the smaller lamb clearly puts this animal at a disadvantage in heat conservation terms. The smaller lamb may also be weak thus adding to its susceptibility. The larger animal may be disadvantaged as a result of a difficult birth process leaving both mother and offspring exhausted. The lamb may be particularly vulnerable if it is not suckled and dried off by the dam sufficiently quickly. Birth weight can be influenced by several factors. Numerous authors demonstrate that male lambs are significantly heavier at birth than females under specific breed/management circumstances (Vosloo, 1969; Saraswat, Seth and Roy, 1968; Wiener et al, 1974) (see Table 4a), but females have a better pre-weaning survival rate than males (Mullaney, 1969; Moule, 1952; Labban et al, 1966; Prud'hon et al, 1968; Marais, 1974; Bhasin, 1968). This general finding (other authors find no sex differences eg: Napier and Mullaney, 1974) may not totally contradict the birth weight effect on survival as a higher proportion of male deaths may be associated with dystocia as a result of increased weight (Gunn and Robinson 1963). Male lambs also may be subject to a greater number of stillbirths than are females (Alexander et al, 1955). Sex differences in susceptibility to cold have been reported for young adult sheep (Slee, 1970) and for

TABLE 4a

SEX - PRE-WEANING MORTALITY RELATIONSHIPS, SCOTTISH BLACKFACE LAMBS BORN AT DRYDEN FIELD STATION 1976-79

	n	♂	♀	SIGNIFICANCE OF ♂ - ♀ DIFFERENCES
Number of lambs born	307	148	159	
Birth weight Kg ± SE		3.73 ± 0.06	3.47 ± 0.06	t = 3.06 P < 0.01
Stillbirths	6	3	3	
Number of pre-weaning deaths including still-births	34	18	16	NS

TABLE 4b

LITTER SIZE - PRE-WEANING MORTALITY RELATIONSHIPS, SCOTTISH BLACKFACE LAMBS BORN AT DRYDEN FIELD STATION 1976-1979

	n	TWINS	SINGLES	SIGNIFICANCE OF LITTER SIZE DIFFER-ENCES
Number of lambs born	307	192	109	
Birth weight Kg ±SE		3.32 ± 0.05	4.08 ± 0.07	t = 9.16 P < 0.001
Number of pre-weaning deaths		23 (12%)	10 (9.2%)	NS

immature rats (Zarrow and Dennison, 1956). In both cases the advantage was with the female. One interesting account of sex effects on survival is found in the Boyd, Doney, Carr and Jewell (1964) account of the feral population (1932 - 1956) of Soay sheep in the St Kilda Islands where there was a marked predomination of females. There is some evidence that disease on occasion caused greatest mortality in the male population.

Pre-weaning survival rate is inversely related to litter size. Harker (1975) and Saunders (1975) (MLC data) report 2 percent mortality for single lambs rising through twins and triplets to 20.7 percent for quadruplets. Some surveys record no litter size effects on pre-weaning mortality. Labban et al (1966) and Wiener (1967) show twins surviving better than singles or triplets. A close relationship between weight, litter size and mortality is reported by Watson and Elder (1961), with heavy singles and light weight multiples being most susceptible (Table 4b). The generally reported inverse relationship between litter size and survival rate to weaning may not be due solely to a birth weight effect per se as demonstrated by Harker, (1975). Multiple birth lambs may well be more vulnerable to chilling not only due to their small size but because the first born may be left unattended until the parturition process is complete. Evidence for this is scarce as there is very little data on observed parturition in the ewe. In situations where multiples show a higher mortality over singles, increased productivity may be more easily achieved by improving the survival and growth rates of single lambs rather than selection for twinning.

(ii) Age and Parity of the ewe. Evidence in the literature of the effect of age or parity of dam on lamb survival to weaning is not

clear. Many surveys show a depressing effect on lamb survival for both older and younger ewes (Sidwell, Everson and Terril, 1962; Lax and Turner, 1965; Prud´hon et al, 1968; Harker, 1975 and McDonald, 1966). In the latter case this was associated with an increase in deaths from dystocia and starvation. Other surveys identify highest mortality rates with gimmers (Matthews and Ogden, 1957; Trail and Sacker, 1967 and Pout, 1974). Again dystocia and desertion culminating in lamb starvation may be involved. Age of dam is significantly correlated with weight of lamb in several surveys (Mullaney, 1969).

Ewe condition prior to lambing has a marked effect on number of lambs born per ewe but only a small effect on subsequent lamb survival (Lax and Brown, 1968). Where effects on the latter are recorded these are likely to be only at ewe weight extremes (Coop and Hayman, 1962). Ewe nutrition has little effect on birth weight (Christenson, Lasler and Glimp, 1976). Newton and Edelstein (1976) at the Grassland Research Institute, Hurley, produced a mathematical model to predict litter size, lamb birth weight, perinatal lamb mortality and ewe weight change during the second half of pregnancy for use with different nutritional programmes. Fairly accurate relationships were obtained in a within flock experiment, but the results were often confounded with breed effects.

It would seem that birthweight exerts an effect on pre-weaning survival rates both directly and indirectly through interaction with characteristics like litter size, sex, ewe condition/age etc. When analysing flock performance (actual or predicted) relative to survival potentials, the structure of the flock should be considered in the above terms in order to identify areas where improvement could

be made.

(iii) Insulation. The newborn lamb has little or no subcutaneous fat at birth (Alexander, 1978), but is able to conserve heat in cold environments by vaso-constriction and the possession of a birthcoat, although the insulative properties of the latter are initially depressed when the animal is soaked in foetal fluid. The traditional approach to investigating the influence of birthcoat is to divide birth coat types into grades, usually about six, from fine to coarse (Ryder, 1974). Several different studies have been carried out using this system. Mullaney (1966) showed birthcoat to have little effect on survival to twenty days, except in one year with a severe winter when lambs with coarser coats seemed to have an advantage. This study contained only a few animals with very coarse coats. Wilcox (1968) also showed no advantage for coarse coat type within the Welsh breed but again this was only in "moderately severe climatic conditions." Significant effects of birthcoat on survival are reported by Obst and Evans (1970) for Merino lambs on Kangaroo Island where mean mortality was 21.5 percent for fine coated lambs and 12.6 percent for coarse coated lambs over a four year period. Significant effects are also recorded by Semmens (1971) although the results here were confounded with variations in weather. The reported heritability of birthcoat type varies from 0.5 (Wilcox, 1968) to 0.6 (Purser, 1967), both using Welsh Mountain sheep. This relationship was exploited by Purser and Karam (1967) in the development of extreme hairy and fine strains of Welsh birthcoat at Rhydyglafes. They found that lambs with intermediate birthcoat types showed better survival rates than either fine or coarse coated lambs.

(iv) Housing - Management - Shelter. Sheep housing, although

becoming more widespread, is still not common practice especially in the hills. Much evaluatory work has been carried out by the Ministry of Agriculture's Experimental Husbandry Farms (Powell, 1978; Meadowcroft, 1978). Housing of ewes around lambing time can eliminate the effects of inclement weather on lamb survival but the economic benefits will be dependant on the severity of weather experienced. Speedy et al (1975) and Trail and Sacker (1966) show no economic advantage from housing , Marshall and Dixon (1969) demonstrate an advantage in terms of reduced lamb mortality in only one year of a three year study when paddock deaths rose to 30.5 percent (previously 10 - 12 percent) due to particularly severe weather conditions. Other surveys show a definite reduction in lamb mortality attributable to housing, Altenkirch and Otto (1953) record a decrease, 29 percent in pre -28 day mortality for fully housed over yarded Merinos. Housing of ewes not only provides environmental protection for the animals but also establishes a situation where observation and supervision by a limited labour force at lambing time can result in fewer deaths from dystocia and mismothering. The economics of supervision relative to environmental conditions has been discussed by Tyrell and Giles (1974).

Comparison among farms is difficult as assessment of management standards is largely subjective. A few controlled studies have been carried out albeit with a relatively small number of animals (Ducker, 1975). This latter study gives a comparison between two different levels of management within housed and outwintered groups of sheep. Deaths were greatest in all less intensive management situations. One demonstration of management technique having a definite effect on productivity is shown by Snook (1970). In this Australian study with

Merinos, which generally have a breed average pre-weaning mortality of about 15 percent, a control group returned mortality of 14 percent compared with 2 percent for a group closely supervised, similar results were found by Giles (1968). Ducker and Fraser (1973) showed level of husbandry to have a significant effect on the quantity of immuno-globulins absorbed by the new born lamb. This effect was partly manifest in lower mortality for the supervised high immuno-globulin group over other groups in the trial.

Shelter rather than custom built housing may provide more economic protection from severe weather. McLaughlin, Egan, Poynton and Thompson (1970) in a study comparing open paddocks, sheltered paddocks and individual penning concluded that sheltered paddocks were a useful alternative to individual penning but results were likely to vary between years. In a further study Egan, McLaughlin, Thompson and McIntyre (1972) demonstrated a reduction from 19 percent to 6.3 percent in mortality up to 48 hours for lambs born out in the open compared with those confined to shelter during inclement weather. Shelter research has been continued in Australia more recently with investigations into Phalaris grass windbreaks which have been utilised in an attempt to reduce lamb mortality by providing shelter from severe weather (Alexander and Lynch, 1976; Egan, Thompson and McIntyre, 1976). In the former case some ewes were shorn in order to reinforce their shelter seeking drive; survival of lambs from these ewes was superior to those from other unshorn dams. Lynch and Alexander (1980) review six years of shelter research at Armidale, New South Wales and demonstrate that sheep can "learn" to use shelter irrespective of the weather experienced. Winfield, Brown and Lucas (1969) demonstrated shelter seeking

activity (for lambing sites) by Welsh ewes when windspeed increased beyond 8 km/hour.

(v) Weather. The effects of weather on lamb mortality can be dramatic, Obst and Day (1968) record a jump from an average mortality of 29 percent for Merinos and Corriedale flocks on Kangaroo Island to more than 91 percent for Merinos exposed to severe weather in the same location. Purser (1967) shows differences in lamb mortality over the first four days from birth in Welsh lambs where mortality levels were 2.7 percent in good weather and 14.3 percent in bad weather. Pout (1974) records no relationship between weather and mortality during the first week of life, Speedy et al (1975) return a very low percent pre-weaning mortality in their hill survey (5 percent) but comment that one reason for this finding was the mild weather experienced during their survey. The variability of weather both within and between different lambing seasons may disadvantage the progress of Natural Selection for improved survival characteristics. A lamb born on a cold, wet night on a hillside will certainly be tested against its compatriots for superior survival traits, but other animals may be born on a warm day with no need to demonstrate their fitness to survive the cold. Coupled with this, ram selection does not usually take "hardiness" into account.

In many countries, if to a lesser extent in Britain, two lambing seasons operate, often with significantly different lamb pre-weaning lamb mortalities occurring in the different seasons. Level of mortality will generally be higher in the more extreme of the seasons (Karam, 1959; Reyneke, 1969; Arnold and Morgan, 1975). Bhasin (1069) shows mortality for Chokla sheep in India decreasing from January through to March.

(B) BEHAVIOURAL FACTORS

The sheep is a social animal, however flock behaviour may be modified in different breeds. For example the Dorset Horn and Southdown do not flock as tightly as Merinos (CSIRO,1976). Behavioural characteristics can be inherited, selective breeding in the Merino has developed their gregarious nature in order to assist shepherding on extensive ranges (Squires, 1975). The extent to which management practices restrict instinctive behaviour patterns may influence survival. Mortality from smothering is rare among wild or extensively ranged sheep which have access to natural shelter, (Blaxter, 1964) but sheep held in open paddocks may mass together and smother in storms (Geist, 1971). The social environment likely to optimise mothering ability is found to be small groups of ewes (Saunders, 1975). Winfield (1970) shows a particularly high proportion of lamb deaths (55 - 61 percent) resulting from desertion by the ewe, in a study where ewes were intensively grouped. Similar results were found by Shelley (1970) where 21 percent of lamb deaths in a high stocking intensity situation were attributable to aspects of ewe behaviour.

The behaviour of the post-parturient ewe relative to lamb survival has been studied by several researchers (Arnold and Morgan, 1975; Bareham, 1976). The early development of the maternal bond would appear to be important, since the lamb left unnurtured by its dam may soon succumb to cold starvation. This bond may be less easily established between young ewes and their offspring than for older more experienced ewes (Saunders, 1975). Ewes appear to be attracted to their newborn lambs immediately after birth by smell and taste (Collias, 1953) although it appears this attraction is not lamb

specific (Alexander 1980). Vocalisation (Bareham, 1976) and visual perception have been demonstrated to play an important part later (Alexander, 1980).

Recognition by ewes of their lambs at birth is not demonstrated (Alexander, 1960; Smith, Van-Toller and Boyce, 1966); a factor which leads to mismothering and abandonment. In the case of multiple parities the second and subsequent parturitions can distract the ewe for some time during which the first born lamb may wander. In this situation other pre-parturient ewes may steal the first lamb and deaths result from mismothering (Arnold and Morgan, 1975). Owens, Bindon, Edey and Piper (1980) found in the Boroola Merino no evidence that maternal behaviour decreased with the birth of consecutive lambs although less active lambs received less attention from the ewe. In this study there was no interaction with weather as all ewes lambed indoors. Once born the lamb seems to be directed to the udder by the ewe's orientation and pushing during the cleaning operation (Alexander and Williams, 1964). Most lambs stand within thirty minutes of birth and drink before two hours but there is wide variation between individuals and breeds (Alexander, 1958). The latter variation may have a genetic component, but environmental factors, prolonged parturition (Shelley, 1970) and poor prenatal nutrition have important predisposing effects (Bareham, 1976). The subjective nature of the tests applied to some behavioural studies will also be responsible for some of the variation. Slee (1981) shows significant breed differences in such behavioural characteristics as "time to suck," "speed of establishment of maternal bond" as evidenced by a ewe - lamb separation test. For these characters feral breeds showed superiority over hill breeds and

Southdowns, Tasmanian Merinos and Finnish Landrace scored relatively badly. This study was confounded by variations in weather causing various degrees of hypothermia in the lambs under test on different occasions. Part of bond formation involves stimulation of the ewe by the active presence of the lamb. Thus the weaker lamb at birth, perhaps disadvantaged by a period of hypoxia during the parturition process, or overcome by environmental conditions, may not get much assistance from the ewe and will be extremely vunerable to cold and starvation. Haughey (1980) cites injury to the foetal central nervous system during the birth process as the main predisposing factor to perinatal mortality. Such injuries are manifest in lambs with depressed sucking drive and locomotor activity making them especially susceptible to demands from their environment. Lamb behaviour is affected by the weather, Alexander and Peterson (1961); Alexander and Williams (1966a,b) and Arnold and Morgan (1975). In the latter study lamb mortality increased significantly in wet weather in the winter. Most lambs dying subsequently had low rectal temperatures at three hours, poor maternal behaviour being cited as the main cause of death in 16 percent of cases, and failure to suck in 23 percent. Activity in lambs, when energy reserves are not replaced and environmental demands are great, falls off markedly. Teat seeking ceases when rectal temperature drops below 37 C (Alexander and Williams, 1966a,b). Moule (1952) cites poor maternal behaviour as one of the major causes of lamb deaths in his study

Provision of shelter and supervision of the flock to reduce the effects of starvation and cold will probably have more effect in minimising lamb mortality than attention to behavioural traits.

(C) GENETIC FACTORS

(i) Breed Differences. The genetics of lamb survival, especially with regard to between breed variation has been dealt with extensively by Wiener over the past few years. Wiener (1966; 1967; 1975); Wiener and Hayter(1975); Wiener, Deeble, Broadbent and Talbot (1973) and Wiener and Smith (1978). In farming practice different breeds of sheep are usually run as separate flocks, often with only one breed represented on one particular farm, thus direct comparison between breeds is confounded by environmental factors. Moreover large numbers of individuals are required to allow statistical analysis of genetic data. For these reasons much of the literature, excluding that of Wiener, is based on data collected from range situations.

Data collected from ABRO's Dryden Farm are shown in Table 5. Direct comparison between all breeds is not possible as some, notably the Merino and Finnish Landrace, were lambed almost exclusively indoors whilst the majority of the other breeds were only brought inside after lambing or at night. MLC data (Saunders, 1975) although not from one environment, show breed differences in lamb mortality to weaning (Table 6). Wiener and Hayter(1975) demonstrate breed differences in survival rate between Scottish Blackface, Cheviot and Welsh Mountain lambs, the latter showing the lowest mortality, and the Cheviots the highest. A similar ranking appears in the ABRO Dryden data presented in Table 5. Nielsen (1970) shows the Texel having a significantly higher mortality over the Oxford, Leicester and German Whitehead Mutton. No breed differences in mortality were found by Matthews and Ogden (1957); Vesely, Peters and Slen (1966) and McGloughlin and Curran (1969). The timing of pre-weaning

TABLE 5

LAMB MORTALITY BY BREED FOR LAMBS BORN ON ABROS DRYDEN FARM 1976-79

BREED	NUMBER BORN INCLUDING STILL BIRTHS	% DEATHS AS STILLBIRTHS INCL. PLACENTAL SMOTHERING	% DEATHS TO WEANING (4 MONTHS) INCL. STILLBIRTHS
BOREray BLACKFACE	35	0	2.9
SOAY	127	0	3.1
OXFORD DOWN	50	0	6.0
WELSH MOUNTAIN	181	42	6.6
SCOTTISH BLACKFACE	307	21	11.1
CHEVIOT	105	40	14.3
FINNISH LANDRACE	165	21	20.0
TASMANIAN MERINO	104	25	23.0
SOUTHDOWN	68	16	27.9
BORDER LEICESTER	77	18	28.5
TOTAL	1219		13.8

TABLE 6 LAMB MORTALITY TO WEANING : MLC DATA

BREED	NUMBER OF FLOCKS	PERCENTAGE MORTALITY TO WEANING
WELSH HALF BRED	22	9.7
SCOTTISH HALF BRED	21	12.7
SUFFOLK CROSS/ SCOTTISH HALF BRED	21	13.2

Adapted from Saunders (1975)

mortality may also be a function of breed, Dickerson et al (1975) show the Cheviot breed with the highest proportion of stillbirths in a nine breed comparison; breed differences for stillbirths are also shown in Table 5. For other breeds or strains lamb deaths may be particularly associated with dystocia (George, 1975; Fogarty, 1971). Wiener (1975) picks out the Cheviot as being especially susceptible to deaths from environmental stress in the form of cold.

(ii) Heterosis. Wiener and Hayter (1975) in their previously cited study, record lambs from crossbred mothers having an advantage in survival across three crossbred types (Blackface X Cheviot; Blackface X Welsh; Cheviot X Welsh) over the respective pure breeds. In a previous study Wiener (1967) did not find any significant improvement in survival for crossbreds over purebreds for similar breeds of sheep, although the Welsh Mountain breed again had the best survival rate of the pure breeds. Heterosis effects are also recorded for Finnish Landrace crosses (Dickerson, Glimp and Gregory, 1975) and for Merino cross Romney over pure Romney, the latter cross showing a 10 percent reduction in mortality over the pure breeds. Dalton (1975) and Sidwell, Everson and Terrill (1962) show a crossbred superiority in "livability" over pure breeds involved in the cross. Such improvements in mortality levels as a result of crossbreeding are not always without undesirable correlated effects. In the study by Dalton (1975) the Romney crosses showed increased susceptibility to foot rot , lower fleece quality and weight when compared with the pure breed. Iwan, Jefferies and Turner (1971) calculated heterotic effect for lamb survival of 3.5 percent for single lambs from two year old ewes and 1.4 percent for single lambs from older ewes, 17.2 percent and 12 percent were calculated

for twin lambs respectively. These calculations were on Merino and Corriedale ewes and their reciprocal crosses. Other studies show no heterosis effect on mortality (Finland, Liland and Gedrem, 1969; Ozcan and Aki, 1974; Nickolić and Josic, 1955 (except in one year)).

The positive (if complicated) effects of heterosis could prove a major contribution in improving the mortality situation if the right cross could be established for a given environment.

(iii) Inbreeding. The viability of lambs generally decreases with inbreeding (USDA, 1952; Sannikov, 1968; Cvumlivski, 1974; Hight and Jury, 1969; and Glembockiĭ, 1956). In many cases, this increase in mortality may be associated with a decrease in birth weight in the inbred population. Ragab , Asher and Kadi (1954) record no effect of inbreeding on mortality in Ossimi lambs. Wiener (1975) demonstrates an effect of inbreeding depressing lamb survival by 27 percent in the first generation of parent offspring mating against outbred Scottish Blackface from the same flock.

(iv) Sire Effects. Little evidence is available in the literature regarding sire effects (not breed of sire) on lamb mortality. Significant effects have been recorded by Goot (1975) for crossbred Finn cross Mutton Merino lambs up to 240 days and Bullov (1968) showed significant variation in survival to weaning from 82.1 - 96.3 percent for Romney Marsh sires imported to Russia from Britain. USDA, (1952) did not find any evidence to support the presence of sire effects in a long term study of Columbia sheep.

(v) Heritability of Survival. Table 7 reviews the heritability estimates for lamb survival found in the literature. The relatively low estimates for heritability are discouraging for progress through direct selection. Little is known about the likely

TABLE 7 HERITABILITY ESTIMATES FOR LAMB SURVIVAL

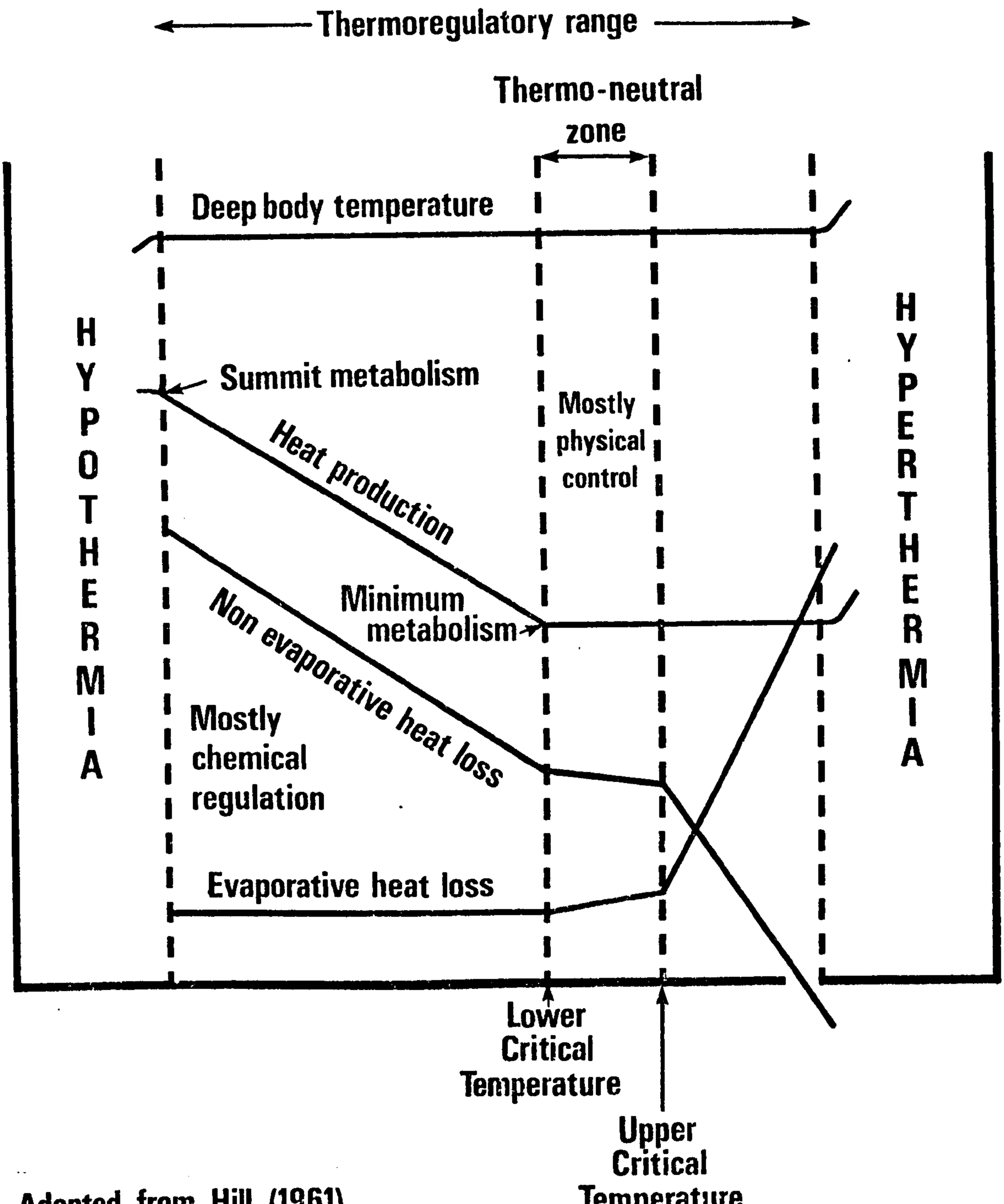
$h^2 \pm SE$	n	DEFINITION	TYPE OF ESTIMATION	BREED	MANAGEMENT	SOURCE
0.131 ± 0.051	4926 (214 sire sub classes)	Survival to weaning	Paternal ½ sib Analysis	Rambouillet	Range A Sub-Optimal Nutrition	Shelton & Menzies 1970
0.190 ± 0.090	1371 (88 sire sub classes)	Survival to weaning	Paternal ½ sib Analysis	Rambouillet	Much higher nutritional level than A. Less attention at lambing	Shelton & Menzies 1970
0.08	366	To 14 days		Nali		Malik & Acharya 1972
0.03	366	15 days to Weaning		Nali		Malik & Acharya 1974
0.06 ± 0.03	3535 Pure bred 3178 Cross bred			Suffolk Hampshire Oxford		Smith 1977
0.02 ± 0.02	35 sires 3521 25.7 off-spring/sire	to 7 days		Merino		Piper & Bindon 1977

contribution of genetic factors involved in cold susceptibility (Slee, 1967; Slee, 1975). Possibly some advantageous and heritable characteristics may be found aiding survival in poor environmental conditions.

(D) PHYSIOLOGICAL FACTORS.

Newborn lambs are homeothermic from birth (Alexander, 1961) but although their heat production systems may be functioning, they encounter special difficulties in maintaining body temperature as a result of being born saturated in foetal fluids into conditions where a large temperature gradient exists between animal and environment. Heat conservation capabilities are greatly reduced over those of the adult for a number of reasons. The lamb's relatively large surface area to body weight facilitates heat loss, coat length and type provide less effective insulation, immobility for a short period after birth prevents shelter seeking and heat production as a result of exercise, and the newborn lamb has little if any subcutaneous fat. Heat production may also be impaired for a period after birth if hypoxia has been experienced during parturition.

(i) Thermoneutral Zone (TNZ). Figure 3 illustrates the widely documented (Hill, 1961; Mount, 1979) generalisation of heat balance for a normal homeotherm relative to environmental temperature. The discussion of this diagram relative to the newborn lamb will pertain to events below the upper critical temperature. TNZ is the range of ambient temperatures within which body temperature regulation is achieved by non-evaporative physical processes alone; (Bligh and Johnson, 1973) by variation in peripheral motor tone and piloerection and changes in body conformation. In any application of TNZ concepts



Adapted from Hill (1961)

Fig.3 Heat balance related to environmental temperature in a homoeothermic animal

to the field situation it must be remembered that ambient temperature alone can not describe the cooling powers of the environment, convection, conduction and radiation effects must also be considered in any heat balance situation.

(ii) Basal Metabolic Rate. The terms Basal Metabolic Rate (BMR) and Minimum Metabolic Rate (MMR) are often used interchangeably in the literature. They are both generally used to describe the metabolic rate of the resting homeotherm experiencing thermoneutrality. BMR more specifically is measured with the animal in a post-absorptive state (Bligh and Johnson, 1973). MMR is more usually used, especially in the case of ruminants, except in cases of precise experimentation. Mercer (1974) recorded MMR of 10.3ml02/kgmin for three hour old Greyface cross Suffolk lambs. He presumed this to be twice as high as the expected maternal level. MMR increased by 50 per cent from birth to seventeen hours to levels of 14.5ml02/kgmin. No further significant change was recorded over the next fourteen hours when estimations were made. Similar estimations have been made by Eales and Small(1980) where a mean value of 10.6 $\pm$ 0.3ml02/Kgmin was determined for thirty nine Scottish Blackface lambs between one and four hours old. Results given by Dawes and Mott (1959) are confused by anaesthetic (Sodium Pentobarbitone) effects but an average of approximately 10.8ml02/Kgmin is recorded, although only four animals were involved in this estimation. The rise in MMR immediately following birth is probably associated with the "switching on" of the self supporting physiological processes in the newborn; increased hormonal activity, muscle toning, activity of the gastro-intestinal tract and respiration. No such rise in MMR occurred in lambs starved for

thirty one hours from birth (Mercer, 1974).

The level of MMR is directly proportional to body weight but this is not a precise linear function (Kleiber, 1932). The higher metabolic rate per unit weight of the smaller animal is as a result of the greater relative surface area increasing the rate of heat loss from the body. Much discussion and experimentation has proposed different precise relationships between metabolic rate and body weight to take account of surface area effects and allow comparison within and between species and has been the subject of much controversy. Surface area is generally represented as an exponential function of weight. The historical evolution of these concepts from the first surface area relationships of Sarrus and Rameaux (1839) to the now more generally utilized exponential functions of body weight founded in Huxley's (1932) allometric growth equations is reviewed extensively by Mount (1968, 1979). A summary of various estimations of MMR body weight relationships together with their special applications is shown in Table 8. The latter part of this table illustrates metabolic rate with a direct linear relationship to body weight in the young animal.

Care should be taken when comparing different experimental estimations of MMR to account for the level of nutrition applied during the estimation. Feeding increases MMR (Close and Mount, 1978).

(iii) Lower Critical Temperature (LCT). The ambient temperature over which the TNZ extends is considerably smaller for the newborn than the adult. A range of 25 - 30^{o}C is given by Mount (1979) and Alexander (1973). Mercer (1974) estimated a range of 35.4 - 37.2^{o}C ambient for the lamb at 3 hours of age. An adult sheep with

TABLE 8 VARIOUS ESTIMATES OF THE RELATIONSHIP BETWEEN MINIMUM METABOLIC RATE AND BODY WEIGHT

ESTIMATION	SPECIES	SOURCE
$M = a\ w^{0.73}$		BRODY (1945)
$M = a\ w^{0.75}$		KLEIBER (1947)
$M = 7.2w^{1.0}$	human babies 10 - 12 Kg	HILL AND RAHIMTULLA (1965)
$M = 15.1w^{1.00}$	Piglets 1 - 6 days	MOUNT AND STEPHENS (1970)
$M = a\ w^{0.9}$	Piglets 82 hrs - 9½ days	STUDZINSKI (1972)
$M = 8.9 \pm(0.13)w^{1.09}$	Lambs 3 hrs n = 34	MERCER (1974

M = Minimum metabolic rate
a = a constant
w = body weight

60mm fleece in windy conditions would have a LCT typically in the region of -3°C (Webster, 1976) and an upper critical temperature in the region of 40°C (Alexander, 1973). LCT decreases over the first few days of life especially after post-parturient drying off of the birthcoat. Mercer (1974) demonstrated a decrease of 11°C from 35.4°C at 3 hours to 24.9°C at 31 hours for lambs. LCT is inversely related to body weight as heat loss from smaller lambs is relatively greater. As MMR rises after birth and evaporative heat loss declines as the wet neonate dries, LCT decreases. LCT will vary with birthcoat type (Alexander, 1973). Starvation may have a small effect in increasing LCT as demonstrated by Mercer (1974) with a 3°C rise after 31 hours of starvation.

(iv) Rectal Temperature. Rectal temperature is used throughout the literature as synonomous to core temperature. Core temperature is specifically defined as the mean temperature of the tissues at a depth below that which is affected directly by a change in the temperature gradient through peripheral tissues (Bligh and Johnson, 1973). However most animal experimenters use the almost standard procedure of measuring and quoting rectal temperatures. The depth at which these temperatures are taken should be defined according to the species involved to facilitate repeatability between readings and allow comparison. The usefulness of rectal temperature as a repeatable and representative measurement of body temperature has been investigated extensively in human physiology. Eichna, Berger and Becker (1951) investigated the use of rectal temperature as a standard parameter by demonstrating it representing the third highest temperature recorded within the body superseded only by liver and brain temperature, both the latter involving much more complex

procedures in their measurement. One disadvantage of rectal over sublingual and external auditory canal temperatures is that the former has a relatively slow response time as a result of a relatively small blood supply and a large heat capacity of surrounding depth of tissue. Another disadvantage was demonstrated by Poole and Stephenson (1977) whereby obstruction of the rectum by temperature probes resulted in an elevation in temperature as a direct consequence. Measurement of rectal temperature also implies a degree of restraint on an animal which may have an influence on normal thermoregulatory responses. For animal work the rectum provides a readily accessible temperature measurement site but it is probably unsuitable for sensitive dynamic studies.

Several researchers have recorded a drop in rectal temperature immediately after birth, the amount of drop and the time taken to reach normal levels is largely dependant on environmental demands (Mount, 1974; Mercer, 1974; Slee, 1977; Alexander and McCance, 1958). Breed variation can also be demonstrated in this degree of post-parturient temperature drop (Fig 4) with Merino, Finnish Landrace and Southdown proving most susceptible of those breeds observed by Sykes et al (1976). The drop experienced by these breeds in colder weather is often sufficient to impose a marked degree of hypothermia; low birth weight individuals are especially susceptible.

(v) Metabolic Response To Cold. Cold induced metabolic heat production as a consequence of chemical energy transformation within the animal is demonstrated in the lamb from birth. As the thermal demands of the environment are increased so metabolic rate increases towards a maximum level attainable. This increase is parallelled by

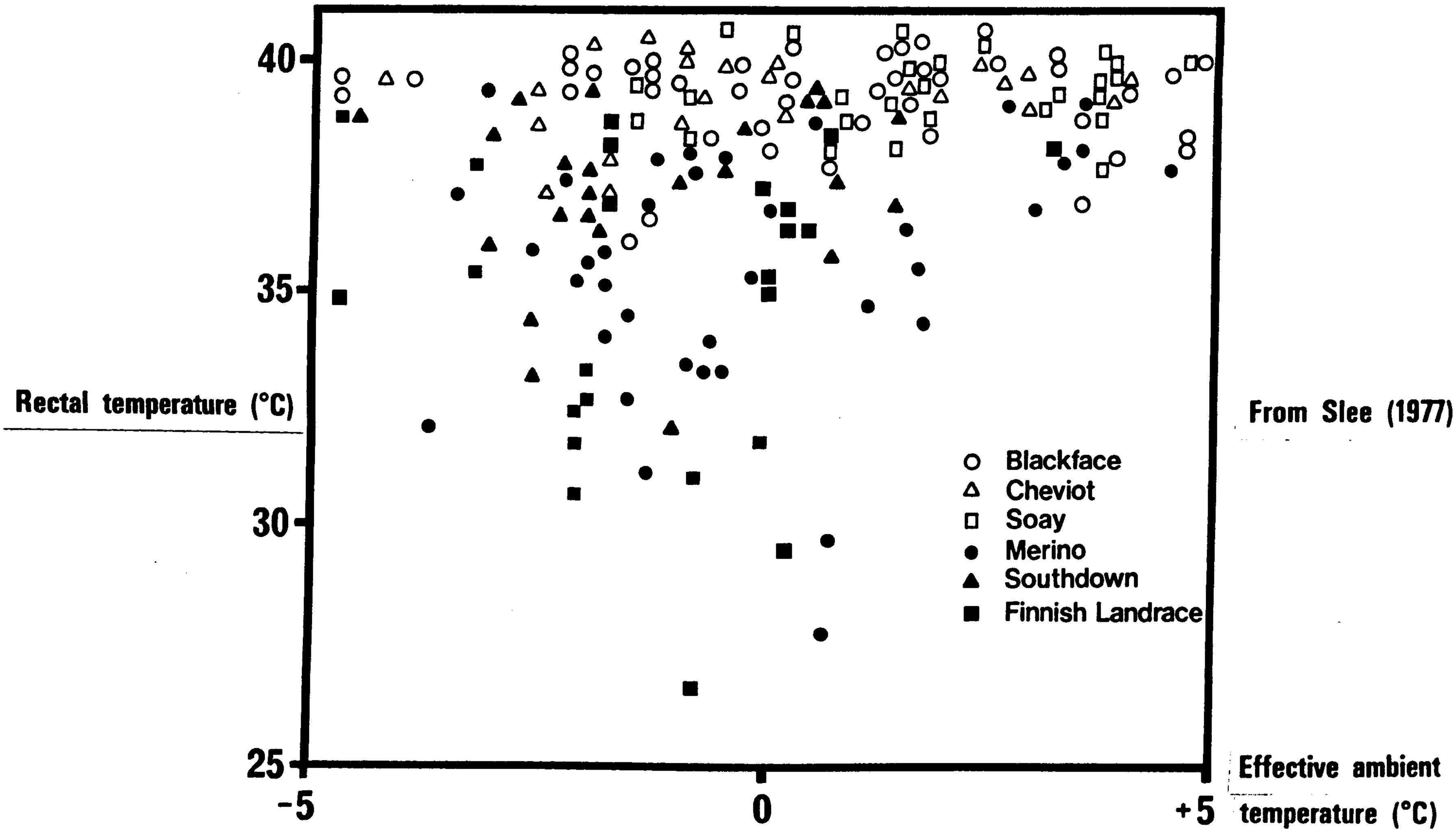


Fig.4 The relationship between the rectal temperature of newborn lambs of six different breeds and the prevailing weather assessed by ambient temperature and wind speed

a slight increase in rectal temperature. Environmental demand is not based solely on ambient temperature as recorded and illustrated in the TNZ concept; wind, rain and solar energy demands can produce huge additive effects to result in a much increased environmental thermal demand on the animal. Summit (SMR) or Peak Metabolic Rate (PMR) is defined by Bligh and Johnson (1973) as the highest metabolic rate that can be induced in a resting animal by a cold environment. This parameter has been investigated in many species, more precise definitions are often given with specific experimental techniques. Estimates of SMR are best made over a period of time as voluntary muscular activity can have a large additive effect over the short term. Bennett (1972) records instantaneous metabolic rates between 2 and 36 percent above the average of a twenty minute period for adult sheep as a direct result of movement and not as a consequence of metabolic response to cold. Researchers vary in their estimates of SMR for specific species and the magnitude of their measurements relative to MMR. Table 9 illustrates some of the SMR levels published for young lambs.

Alexander and Williams (1968) tabulate the effects of various drugs on SMR. In general all sympathetic inhibitors depress SMR. Results shown in Table 9 are from experiments where no such preparation was administered.

SMR is not dependant on rectal temperature if this is close (1 - 2 ^{o}C) to normal body temperature and is probably best measured as rectal temperature starts to fall during a continuous cooling regime. Such a measurement is more comparable with others as the animal is not exhausted to varying degrees of energetic effort if the period is prolonged. Once rectal temperature has started to decline rapidly

TABLE 9 ESTIMATIONS OF SUMMIT METABOLIC RATES FOR YOUNG LAMBS

SMR ml O_2/Kg min	n	Age	Breed	Source
47.6 ± 1.83	29	1 - 4 hrs	Scottish Black-face and crosses	Eales (1980)
≈ 52.9	19	< 9 hrs	Merino	Alexander (1962)

metabolic rate will decline in parallel. Alexander (1962) extrapolates this linear decline and estimates zero metabolism at around 23°C rectal temperature for the Merino lamb with a rate of decline of just over 4ml02/Kgmin/°C. Fasting has also been demonstrated to depress potential SMR. The length of time summit metabolism can be held may depend on level of energy reserves but feeding prior to experiment does not improve performance (Alexander, 1962). The effect of posture on SMR in young lambs has not been investigated but for adult sheep there is a marked reduction (27 percent) in the lying over the standing animal (Bennett, 1972). Rectal temperature drops much faster in the lying animal probably as a consequence of reduced heat production from shivering as the leg muscles (equivalent to half total body shivering muscle) are effectively insulated. Eales (1980) finds SMR to be more closely related to body surface area than to body weight Other researchers have found direct relationships with weight for lambs and pigs (Alexander, 1972; Mount and Stephens, 1970).

(vi) Heat Loss. The laws of physics governing heat loss via the processes of conduction, convection, radiation and evaporation apply as much to the homeothermic animal as to an inanimate object. The newborn lamb like other homeotherms can influence to some extent the rates of heat loss via these processes.

(a) Conduction. Conduction or the transfer of heat by direct contact occurs directly through the body tissue to the skin surface and from the skin surface through materials in direct contact. Conduction is most important when the animal is immersed in a medium of high conductivity such as water. The lamb which falls into a mountain stream will very quickly develop hypothermia;

similarly the newborn lamb soaked in foetal fluids or drenched with rain will be more vulnerable to heat loss as the sodden fleece loses much of it's insulative properties. Heat loss via conduction depends on the surface temperature and the effective area of contact and is especially important for lying animals. It has been calculated that a sheep lying on poorly insulated ground in a cold environment can lose up to 30 percent of it's minimum heat production via conduction (Gatenby, 1977).

(b) Convection. Convection is a form of heat transfer which depends on the redistribution of molecules, particles of air or water in contact with the body which have been heated by conduction. Warm air surrounding a body rises as it is less dense than colder air, hence natural convection currents are set up. The body at rest is surrounded by a warmer layer which acts as an insulator. The layer is easily disrupted by a light breeze (Moore, 1975) and forced convection occurs. The newborn animal can lose heat by convection from the core to the skin surface via the blood stream, by convection through the moving air stream at the skin surface and through the transfer of warmed inspired air to the exterior in expiration (Swyer, 1978). Heat exchange by convection depends on body surface temperature, it's shape, surface characteristics and size, and on the rate of movement and temperature of the air that impinges on the body (Mount, 1979). In windy and wet conditions it is convective heat loss which will have most effect on the rate of heat loss from the animal.

(c) Radiation. Radiation is the process of transfer of energy by non-particulate means. The infra-red portion of the electro-magnetic spectrum is involved and radiant energy is

transferred down a temperature gradient from the animal's skin to surrounding cooler surfaces (Swyer, 1978). The amount of heat loss is a function of the temperature gradient between the exchange surfaces and their effective surface areas. Heat loss from radiation can be serious on clear nights when the body surface may exchange with cold outer space (Moore, 1975).

(d) Evaporation. Evaporation occurs in three ways, **insensible evaporation from the skin surface, evaporation of sweat** and evaporation from the mucosa of the respiratory tract. Every gram of water lost from the body by evaporation involves 0.58Kcal of heat loss (Swyer, 1978). For the newborn lamb, enforced cooling by evaporation of water as foetal fluids dry out may cause considerable cold stress although theoretical values of latent heat exchange may not be reached due to the water holding capacity of the fleece (Alexander, 1973).

(e) Insulation. Heat loss from lambs varies according to the insulative properties of their birthcoats (Alexander, 1961; 1962a; 1962b) At $0^{o}C$ heat production of short coated Merino lambs is doubled over thermoneutral levels and application of 20 Km/hr wind trebles the base value. Wetting the coat will have a further additive heat loss effect. Long coated lambs of the same breed show similar responses but to a lesser extent (Alexander, 1962b). Tissue insulation in lambs in the cold is about $0.15^{o}C/m/w$ and is equivalent to fleece insulation for long coated lambs, the latter is reduced to levels of around 0.05^{o} C/m/w for short coated Merinos (Alexander, 1973). Post-natal growth of fleece is generally rapid and insulative properties increase accordingly. Vaso-constriction is effective in tissue insulation from birth (Alexander, Bell and Hales, 1973).

Various factors will effect greater heat loss in a cold environment, these include: wind, wetting, exhaustion, injury, drugs and hypoxia. Factors decreasing heat loss are: insulation, huddling, shelter, solar radiation and exercise (Moore, 1975).

Evidence of adaptive changes to cold in the newborn lamb either by habituation (passive reduction of body temperature under mild cold exposure) or acclimatisation (increased metabolic rate providing greater resistance to body cooling) is not found in the literature. Sykes (1968) showed a slight acclimatisation effect in lambs kept in dry cold for two weeks following birth. This was demonstrated in an increased resistance to body cooling over a control group of lambs which had been exposed to near thermoneutral temperatures but involved only a small number of animals. Slee (unpublished) has not been able so far to repeat this finding using a waterbath cooling technique as a method of testing resistance to body cooling.

(vii) Non-Shivering Thermogenesis. Non-shivering thermogenesis (NST) may be defined as a heat production mechanism liberating chemical energy due to processes which do not involve muscular contractions (Jansky, 1973). Although Claude Bernard first carried out experiments in 1876 demonstrating NST, conclusive supportive evidence was not available until the mid 1950's. Much of the confirmatory work was carried out in cold acclimated rats (Hart, Heroux and Depocas, 1956; Sellers Scott and Thomas, 1954; Cottle and Carlson, 1956). Following this initial work, the site of non-shivering thermogenenic activity within the body was investigated and in the early 1960's brown adipose tissue (BAT) was identified (Smith, 1961; Dawkins and Hull, 1964). Since this time evidence has accrued on the presence of functioning BAT in the newborn of many

species including rabbits, guinea pigs, sheep and hamsters (Dawkins and Hull, 1964; Hull and Segall, 1965; Bruck and Wunnenberg, 1965a,b; Alexander Bennett and Gemmell, 1975 and Rink, 1969). The distribution of BAT in the body of the lamb is mainly in the abdominal cavitity, covering lymph nodes and kidney and around the prescapular lymph nodes (Alexander and Bell, 1975; Alexander et al, 1975). More recently evidence has been presented on other sites of NST activity such as muscle and liver tissue (Janský, 1971; Stoner, 1973) and a role for NST in the adult of certain species has been hypothesised (Rothwell and Stock, 1979). NST and BAT have been reviewed extensively by numerous authors during the last twenty years (Janský, 1973; Brück, 1970; Hull and Hardman, 1970). Alexander (1979), in a comprehensive review on cold thermogenesis devotes a large section to current findings on NST and BAT, discussing many of the more controversial points in detail.

BAT may be defined as any adipose tissue that during its development functions to release chemical energy (Hull and Smales, 1978). Using the electron microscope it is distinguishable from white adipose tissue by the structure of the mitochondria. When active it is specifically identifiable with a light microscope as multilocular cells with granular cytoplasm. Biochemical identification is also now possible by analysis of mitochondria structures and metabolites (Lindberg, Bieber and Houstěk, 1976). Possession of brown fat may be a special adaptation for survival in the neonate during the first few hours of life when the coat is drying out and heat loss to a cold environment is potentially maximal (Alexander, 1979). Heat production as a result of NST is likely to be particularly important for homeotherms born into open rather than

nest environments to prevent temperature drop and the onset of hypothermia. Recent studies by Sack, Beaudry, De Lamater, Oh and Fisher (1976) suggest umbilical cord cutting as the trigger for onset of NST activity rather than stimulation by cold itself. In this experiment newly born lambs with intact umbilical cords were warmed in a waterbath at 39°C. At the end of 60 minutes half the group had their cords cut as they were removed from the bath whilst the others were held under equivalent conditions with their cords intact for a further 60 minutes. In the latter group rectal temperature fall was continued until some minutes after cord cutting and was so rapid that two of the lambs died as a result of hypothermia whilst the former group followed the normal pattern of slight drop and then recovery to normal levels.

The advantages of non-shivering over shivering thermogenesis to the newborn are in that the movement of shivering muscle results in increased air movement around the animal thus reducing external insulation. A violent shivering response may interfere with locomotory co-ordination and hinder teat seeking at an important stage in maternal bond initiation. NST also allows the neonate to maintain homeothermy under environmental conditions much more stringent than if it only had recourse to shivering thermogenesis (Alexander and Williams, 1968).

The relative contribution of the shivering and non-shivering components of cold thermogenesis has been the subject of numerous investigations many of which are discussed by Alexander (1979) and Janský (1973). Full discussion of the limitations of these various techniques is given in the former of these two reviews. Quantification of NST as a result of noradrenaline infusion under

thermo-neutral conditions has been used in many species including sheep (Zeisberger, Brück, Wünnenberg and Wietasch 1967; Alexander and Williams, 1968; Mejsnar and Jansky, 1971; Karlberg, Moore and Oliver, 1962). The application of exogenous catecholamines to facilitate measurement of the thermogenic capabilities of NST is subject to debate as there is confusion throughout the literature as to whether the heat produced is largely additive or substitutes for the metabolic response to cold (Jansky, 1973). In order to overcome this problem the animal under determination must be maximally stimulated by cold or the catecholamine prior to application of the process under quantification. No muscle activity should be present (Alexander, 1979).

Generally the level of metabolic response induced in the newborn by noradrenaline is of the order of one to two times minimal metabolic rate (Jansky, 1973; Alexander et al, 1975). For the lamb NST is maximal immediately post-natal and declines during the first month (Alexander and Williams, 1968). This decline is paralleled by the disappearance of BAT (Gemmell, Bell and Alexander, 1972). This disappearance initiates in the cardiac and intermuscular deposits (Gemmell et al, 1972) and is generally a replacement of BAT by white adipose tissue. Reconversion at a later time of cold stress does not appear to occur in the sheep (Webster, Heitman, Hays and Holynyk, 1969). The rate of decline may be retarded by exposing the animal to cold during early post-natal life (Alexander, Bell and Williams, 1970).

In the sheep brown fat first appears in the latter half of gestation (Gemmell and Alexander , 1978). Changes in the amount found in the neonate may be affected by manipulation of the mother's

diet. In some species a short period of starvation in the latter stages of gestation (2 days) increases the lipid content of BAT in the rabbit (Edson and Hull, 1977). Alexander (1974) demonstrated prolonged maternal undernutrition, resulting in depressed foetal growth in the sheep, to greatly reduce the proportion of BAT in the newborn. Exposure of pregnant rats to cold results in increased BAT activity in the newborn (Hyvärinen, Pasanen, Heikwa, Heinineva and Latu, 1976). No similar evidence is available for other species.

In a sophisticated experiment Heim and Hull (1966) used newborn rabbits to measure blood flow and venous oxygen saturation through BAT before and during noradrenaline infusion. They estimated that BAT accounted for more than two thirds of the extra oxygen consumed by the rabbit in maximal response to cold. A similar estimation was made in newborn lambs drawing on a number of related experiments (Alexander and Bell, 1975; Alexander and Williams, 1970; Alexander, Bell and Hales, 1973; Alexander and Bell, 1975b, Alexander and Williams, 1968). Using data obtained in all these experiments Alexander has estimated that BAT metabolism alone during summit metabolism in the lamb would account for all the 40 percent of SMR attributable to NST.

Detailed mechanisms for the control of shivering and non-shivering thermogenesis in the sheep are extensively reviewed by Alexander (1979).

4. PHYSIOLOGICAL CHANGES AS A RESULT OF IMMERSION IN WATER.

The advantages in speed of body cooling by immersion in water over rates achieved in air are as a result of the high conductivity of water. The advantages in time saved are achieved at the expense

of modification of some of the relevant physiological responses to cold. Although it is remembered that the experimentation to be reported here is of a comparative rather than absolute nature, an awareness of these effects is necessary.

Once immersed in water (excluding the head) the body is affected by both atmospheric and hydrostatic pressure. The latter increases with depth of water and thus pressure over the body is not uniformly distributed. As respiratory exchange is with atmospheric air the immersed subject is forced to negative pressure breathing. This pressure has been estimated at 20cmH20 for the human subject (Hong, Cerrettelli and Cruz, 1969) but will not be as great as this for the lamb as it is both much smaller in height and not positioned in the water as the human. As a result of this intrapulmonary negative pressure together with the level of hydrostatic pressure on the abdomen the expiratory reserve volume will be decreased when compared with values estimated for subjects standing in air. This depression can be up to 70 percent (Hong, Tung, and Rahn, 1960). Vital capacity decreases during immersion so there is a rise in inspiratory capacity. Most importantly (Hong et al, 1969) a 60 percent increase in work of breathing is found. Venous return is also facilitated as a result of pressure gradient changes between extra- and intra-thoracic regions coupled with cold water peripheral vasoconstriction resulting in further increase in central blood volume.

Much detailed work has been carried out in this field with human subjects (Risch, Koubenec, Beckmann, Lange and Gauer, 1978: Farhi and Linnarsson, 1977). Animal work in this field has generally been using immersion as a body cooling technique rather than an

examination of the physiological changes involved (Eales and Small, 1980; Morhardt, Fleming, McCrum, Molt and Miller, 1975).

EXPERIMENTATION

INTRODUCTION AND EXPERIMENTAL HYPOTHESIS

Cold exposure at birth and in the early post-natal period is unavoidable for the newborn lamb. To survive this stress the lamb, as a true homeotherm from birth (Alexander, 1961), possesses fully functional heat production and conservation mechanisms. If these mechanisms are inadequate for whatever reason, some degree of hypothermia will be imposed.

If the ability to combat hypothermia is an important component of early post-natal survival, which is clearly implicated in the Literature Review, and if the components of cold resistance in lambs can be expressed and reliably measured under controlled repeatable conditions, and if there is adequate additive genetic variance within existing breeds, then genetic selection for such a characteristic could have an important indirect effect on lamb survival.

The present work aims to define and quantify cold resistance, to study its physical and physiological components and to identify any within or between breed variation in these. For this purpose a standard controlled cold stress test was developed. Much preliminary work was carried out to identify a suitable procedure (Slee, Griffiths and Samson, 1980). In order to identify areas of useful genetic variation, especially where different breeds are involved, a large number of animals must be tested. The test applied must, as far as possible, relate to field conditions of cold stress likely to be experienced by the newborn lamb. The test must be standardised and repeatable between animals, and not subject to variation in the

level of cold stress applied as would be the case in a field study due to variations in the components of weather. It must be severe enough to induce a measurable level of hypothermic stress (measured by depressed rectal temperature) but not so severe as to prevent the expression of variation in cold resistance between individuals. The length of the test should be such that a number of animals can be tested within one day and should allow an individual to be returned to it's dam without interfering, with the maternal bond or with the subsequent health of the lamb. A large number of individuals will have to be tested within the breeding season. It must be possible to measure relevant physiological parameters throughout the procedure in such a way as not to interfere with the lamb's natural thermogenic responses.

The cooling of Welsh Mountain long-coated lambs with dry cold air and wind in a climate chamber, even with a cooling regime with temperatures falling from 0°C to -20°C, provided a very standardised procedure, but it took on average 245 minutes before rectal temperature could be demonstrated to drop through one degree Centigrade (Slee, 1978). In order to reduce this period, recourse was taken to the high heat conductivity properties of water and a waterbath procedure was developed. This situation may not be too far removed from natural conditions when the newborn lamb is saturated in foetal fluids or drenched with rain water. In preliminary studies a technique involving immersion of the lamb (excluding the head) in a water bath at 25°C with subsequent controlled lowering of water temperature according to a standard time scale was used. Cold resistance was defined as the period in minutes for the rectal temperature of the lamb to fall to 35°C and was measured from the

point of immersion. Results for seven breeds using this preliminary technique are reported in the included paper (Slee, et al, 1980). This procedure allowed easy separation of breeds but is unsuitable for metabolic rate studies where a steady period at thermoneutral temperatures is required prior to cooling in order to establish base oxygen consumption readings followed by a slow and steady cooling rate to allow expression of a maximum metabolic response to cold, not limited by depressed rectal temperature as a result of cooling too quickly. A brief description of the developed procedure together with preliminary results for cold resistance is given by Slee, et al, (1980). Full procedural description, (except for metabolic rate measurements) together with analysed results is given by Samson and Slee (1981).

The experimentation to be reported is an extension of this preliminary work, and already published results will only be included where comparison is to be made.

EQUIPMENT

(A)Indirect Open-Circuit Calorimetry. Indirect calorimetry as applied in this study involves the determination of heat production by measurement of the animal's oxygen uptake. The conversion from oxygen uptake to heat production is based on the law of constant heat sums, which can be deduced from the law of conservation of energy but was actually formulated earlier than the more general law:-

HEAT PRODUCTION = HEAT LOSS + EXTERNAL WORK + HEAT STORAGE

Heat production is generally quoted in this experimentation in units of metabolic rate (ml O2/Kg min) rather than heat units (KJ) as it was oxygen consumption that was actually measured. Metabolic rate may be defined as the total free energy production of an organism per unit mass in unit time. Free energy production being the rate of transformation of chemical energy into heat and mechanical work by aerobic and anaerobic metabolic activities within the organism (Bligh and Johnson, 1973). For an animal without net synthesis of body tissue or products such as eggs and milk, metabolic and catabolic rates are equal as there is no net anabolism. If the animal does no external work then catabolic rate is equal to the rate of heat production. Measurement of this rate from chemical changes within the animal is termed "Indirect Calorimetry." Metabolic free energy production may not all be as a result of aerobic processes and therefore evaluations based on oxygen consumption alone may be slightly depressed.

Open-circuit techniques have been extensively developed since the early apparatus of Haldane and Pettenkofer (Mount, 1979). Historical developments have been well documented by various authors (Lusk, 1928; Brody, 1945; Kleiber, 1975).

Conversion from metabolic rate units to heat production units is by use of the Brouwer equation (Brouwer, 1958, 1965) as shown below:-

$$M = (16.2 \times O2) + (5.02 \times CO2) - (2.17 \times CH4) - (5.99 \times N)$$

M = Heat Production (K.J.)

O2 = Volume (l) of oxygen consumed

CO2 = Volume (l) of carbon dioxide excreted

CH4 = Volume (l) of methane excreted

N = Quantity (g) of nitrogen excreted

Much debate has gone into the validation of open-circuit techniques (Kappagoda and Linden, 1972; Wagner, Horvath, Dahms and Reed, 1973; McClean, 1972). McLean (1972) has shown for ruminant open-circuit calorimetry, heat production can be measured (± 2 percent) by measurement of oxygen uptake and ventilation rate alone.

$$M = 20.47\ Q\ X$$

M = Heat Production KJ

Q = Flow rate of outlet air (litres per unit time).

X = inlet-outlet fractional concentration difference of oxygen.

20.47 = Thermal equivalent for oxygen.

Using this equation variation in respiratory quotient (RQ) could only cause a maximum theoretical error of 1 percent for a change from 1.0 to 0.7 (McLean, 1978). The methane and carbon dioxide components of the Brouwer equation largely cancel each other out, both will be altered significantly by feeding. The nitrogen excretion term is small and meaningless unless measurement is continued for 24 hours.

With these theoretical and practically proven assumptions indirect calorimetry based on accurate measurement of oxygen consumption can be used successfully to determine heat production, especially for short term measurements. Accurate, repeatable equipment is required for measurement and recording of both gas flow rate and composition.

One problem of indirect calorimetry is the capacity of the chamber in which the animal is placed. The volume of air in the chamber is usually relatively large when compared with the volume of circulating gas in the system and a period of equilibration is required before measurement is possible (Mount, 1979). This problem can be overcome by use of a face mask. Comprehensive reviews of the different techniques of respiration calorimetry are found in Flatt (1969) and Blaxter (1971).

A diagramatic scheme of the calorimetry system used in these experiments is shown in Fig.5. The animal was situated in a custom built cabinet which housed the waterbath, drying towers and airflow meter. The gas analysing and data logging equipment was in an adjacent room. Oxygen concentration of inspired (reference) and expired (sample) air and air flow rate were monitored continuously and recorded at minute intervals. Equilibrium in the system was achieved rapidly (after one minute) as the dead space was minimised by the use of a close fitting animal anaesthesia mask (Hall's mask, Arnold's Veterinary Products Ltd., England) adapted to allow both inlet and outlet of air supply by gas tight addition of a 20ml plastic syringe body. Care was taken when fitting the mask to ensure that both inlet and outlet pipes were not occluded by the animal's nose. A variety of mask sizes was used to accommodate different breeds and sizes of lamb. The open end of the mask was lined with a strip of foam to prevent gas escape, although elimination of intake of air through this route was not necessary. All joints were made airtight. Mask design for the Southdown breed (and some Merinos) was particularly difficult as the nostrils are located to the top of the nose rather than at the point, so when the animal opened it's mouth

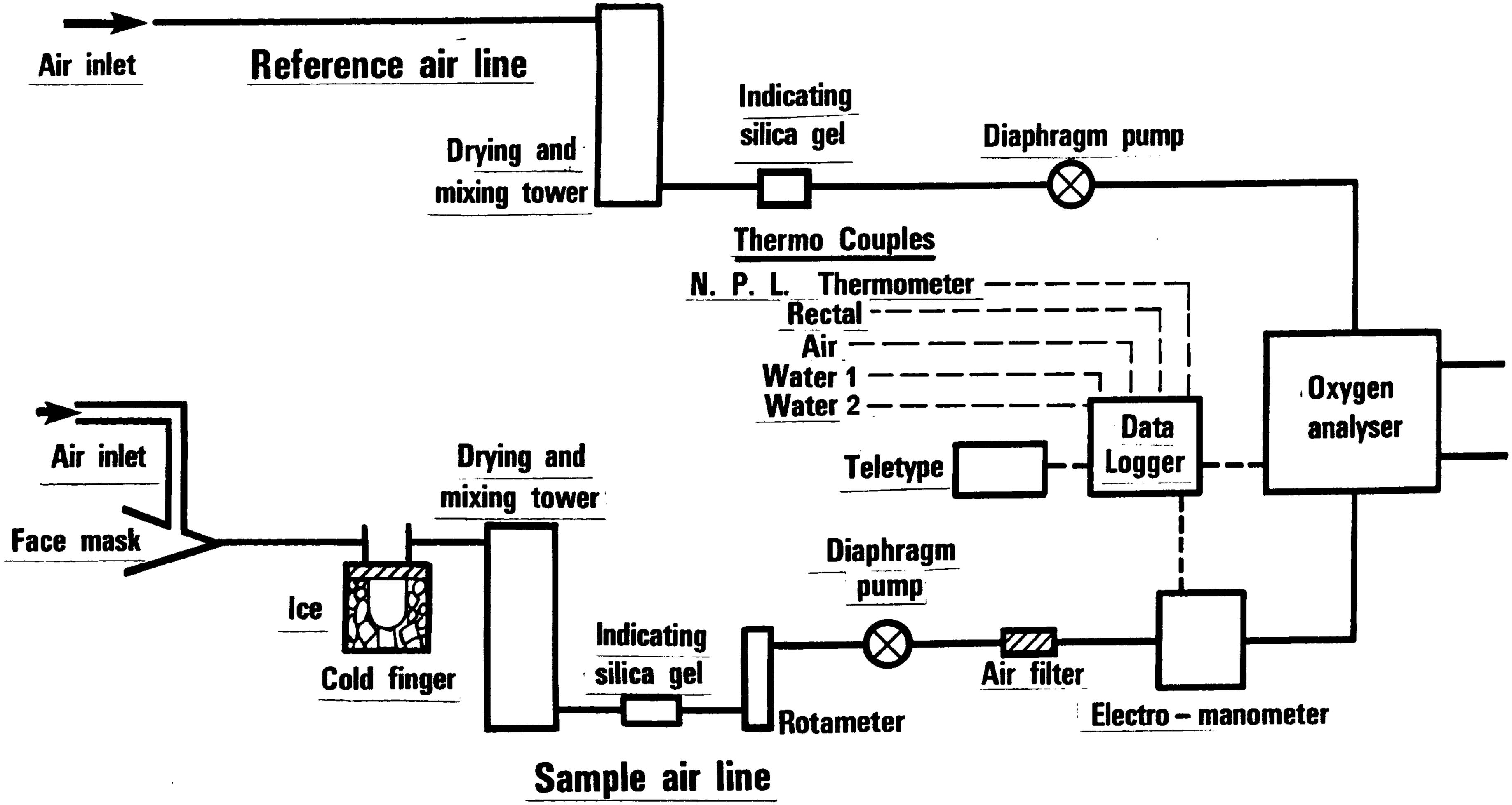


Fig 5 Indirect open circuit calorimeter

to bleat or pant etc., the nostrils could be occluded against the top of the mask fabric.

Air was drawn through both Reference and Sample gas lines by two separate diaphragm pumps (Charles Austen, Duplex 2F 62Watt). Inlet air for both lines was drawn from outside the building. The inlets were juxtapositioned to prevent partial pressure differences and consequent oxygen concentration differences between lines. Care was taken to site inlets away from any contamination source such as exhaust fumes. A coarse air filter was fitted at the inlets to prevent large particles of dust reaching the diaphragm pumps. The rate of air flow was controlled and measured by a flow meter of rotameter type (GEC/Elliott 1100) and more accurately measured by an electro-manometer (M7 Mercury Electronics, Glasgow) linked into the data logging system. This latter device was calibrated regularly against a wet gas meter to ensure accurate measurement. A glass wool filter was incorporated pre-flow meter to prevent any dust particles reaching either the flow meter or analyser. Excess moisture was removed, post-animal, from the sample air stream as it passed through a "Cold Finger" device (Mercer, 1974). This consisted of a sealed glass "U" tube with inlet and outlet pipes near the top (Quickfit Ltd). The body of the tube was immersed in an insulated flask containing crushed ice. Moisture in the air stream condensed on the sides of the tube and collected in the bottom. This condensation was removed between tests. Final drying was achieved in both air lines by drying towers containing calcium sulphate crystals (Ducal Dririte). Use of the cold finger allowed extension of the life of the expensive Dririte, which although reusable after drying out in an oven at 200 ^{o}C for two hours, does deteriorate in water holding

capacity over a period of use. Passage of air through the drying towers served to mix the constituents and allowed a smaller representative sample to be piped off to the oxygen analyser (Servomex OA 184 Servomex Controls Ltd., England). It is especially important that the analyser receives only dry air for analysis. In order to check the efficiency of the in-line drying, self-indicating silica gel crystals were placed in the line prior to the filter and analyser. The outlet from the analyser also passed through silica gel to identify and prevent any moisture re-entering the analyser. Although the silica gel crystals were used as a safety measure, drying agent was changed very frequently and before the crystals changed colour, as it was appreciated that there was a time lag in the indicating colour reaction to the presence of moisture.

When designing the calorimetry system care was taken in positioning the pumps to ensure as much of the gas system as possible was under negative pressure so as to minimise the effects of leaks of expired air to the outside. Pipe diameter was such as to prevent back pressure in the system especially in the supply to the face mask. Even when the pipe network was extended (35 feet) to reach the climate chambers in the later wind tunnel experiments the pressure at the face mask only increased to -0.5 inches water gauge from the normal - 0.3 inches water gauge for operation in the lamb cabinet. Leaks were checked for on a routine basis by sealing off the air line under positive pressure and attaching to a simple mercury manometer. Any change in the level of the mercury meniscus over a period was noted and further checks carried out to locate the leak. Air flow rate was maintained at a sufficient level to prevent interference with respiratory rate due to build up of carbon dioxide in the face

mask. At 15 litres per minute air flow, potential carbon dioxide concentration can be calculated as follows:-

$$[CO2] = \frac{(PMR \times \text{body weight} \times RQ) + 0.03}{\text{air flow rate}}$$

(i) For maximum animal size:-

PMR = 43.94 ml02/Kgmin

Weight = 8.8 Kg (largest lamb)

RQ = 0.9 (Eales, personal communication).

0.03 = % CO2 in atmosphere.

Potential carbon dioxide concentration = 2.3 percent

(ii) For average experimental conditions:-

PMR = 55 ml02/Kgmin (average lamb SMR)

Weight = 3.6 Kg (average lamb weight)

RQ = 0.9

Potential carbon dioxide concentration = 1.2 percent

For the larger animals as in calculation (i) an attempt was made to increase flow rate but improvements possible were only in the order of 7 percent due to pump capacity limitation. It is appreciated that carbon dioxide levels may be increased above these calculated values for expired air as mask design must incorporate some degree of dead space, but this probably will not increase the normal anatomical dead space by any significant amount. Throughout indirect calorimetry design, levels of 1 - 3 percent carbon dioxide have generally been accepted during experimentation especially where measurements are

short term. Operational levels are largely governed by the limitations of gas analysing equipment. The oxygen analyser is required to measure accurately, minimum differences of 0.5 percent between sample and atmospheric gas. This accuracy is achieved with air flow rates of the order of 10 - 15 litres/minute for the lamb (BMR average 15.6ml O2/Kgmin; PMR average 55mlO2/Kgmin). To allow levels of carbon dioxide within the system to be below theoretically physiologically acceptable levels of 0.5 percent, flow rates would need to be increased to somewhere in the region of 200 litres/minute which would clearly be unacceptable for accurate oxygen consumption measurement in the lamb. Blaxter (1962) shows carbon dioxide levels of 1 percent to produce only small changes in respiratory frequency. Eales (personal communication) working with newborn lambs over short periods of exposure (2 - 3 hours) recorded no significant related changes in PCO2 working with a flow rate of 20l/min. Harrison and Smith (1981) working with human subjects in a study of long term exposure to 1.5 percent carbon dioxide show an increase in resting tidal volume of 15 - 20 percent but no increase in respiration rate. In the experimentation reported here the response to cold stress is likely to be far more important than any influence by carbon dioxide and oxygen supply at summit metabolism is probably much more limiting than any build up of carbon dioxide.

The Servomex Oxygen Analyser has been used in many indirect calorimetry studies (Mercer, 1974; Kappagoda and Linden, 1972). It is a twin channel analyser utilising the paramagnetic properties of oxygen, the concentration of which causes a measurable deflection of a suspended dumb-bell. One channel was used to measure reference (normal atmosphere) gas and the other the expired sample gas. The

difference between these is the "oxygen consumption," which is computed internally, all three measurements being outputted to a digital voltmeter (DVM) (Solartron Compact Logger 3430). DVM reliability was increased by addition of a constant voltage transformer (Volstat - Advance Electronics Ltd, England) to prevent corruption of results by electrical mains power surging or interference. The system was also extensively screened, especially exposed lengths of thermo-couple wire, used in temperature measurement, in order to prevent any data corruption. The accuracy of the analyser was improved by applying a correction for barometric pressure before each run. Partial pressure of atmospheric oxygen is a function of barometric pressure. For example, assuming the oxygen content of the dry fresh air to be 20.95 percent at 1000mb.

Then for barometric pressure 945mb:-

$$\text{Oxygen Content} = \frac{20.95 \times 945}{1000} = 20.85 \text{ percent.}$$

The oxygen analyser was then calibrated to operate for the range 0 - 20.85 percent oxygen concentration. The maximum period between calibrations was of the order of three hours and more usually two. Only on two occasions in a three year period did any appreciable change in barometric pressure occur during a single test, ie, between calibrations. These situations were detected by a post-test calibration and the necessary adjustment to the data were made. The setting up procedure was largely according to the Servomex manual as recorded by Mercer (1974). The analyser amplifiers were set to zero with the gas conditioning lamps, feedback system and pumps off, next

with lamps and feedbacks on and pumps running the amplifier zeros were adjusted and the span controls on both channels set to the barometric pressure corrected oxygen content value. Finally a check was made on the "difference" reading between sample and reference channels to ensure this was at zero.

Each cell of the analyser was initially examined for linearity of response to varying flow rates through the cells. Both were found to be linear over the range 65 - 70 percent of total flow possible through the cells as denoted by the integral flow meters on the analyser. Thus the analyser was always operated within these ranges in order to improve accuracy. These flow meters were not considered accurate enough to measure gas flow as used in the oxygen concentration calculations.

Periodically, generally at least once per week, the analyser was calibrated with dry white spot nitrogen gas. No appreciable drift was recorded from these settings except in the case of malfunction of one of the electronic components of the analyser, or movement of the critical position of the parabolic mirrors inside the analyser measuring cells. Realignment was carried out when this proved necessary.

Calorimetry system advice was taken initially from Drs McLean, Hannah Research Institute Ayr; Pullar, Rowett Research Institute, Aberdeen and Lundy, Poultry Research Organisation, Edinburgh.

(B) Waterbath. The waterbath equipment is shown in Fig 6. The tank (approximately 20 gallon capacity) was constructed (Mr.G.Newall and Mr.D.Toghill, at the Genetics Institute Workshop,

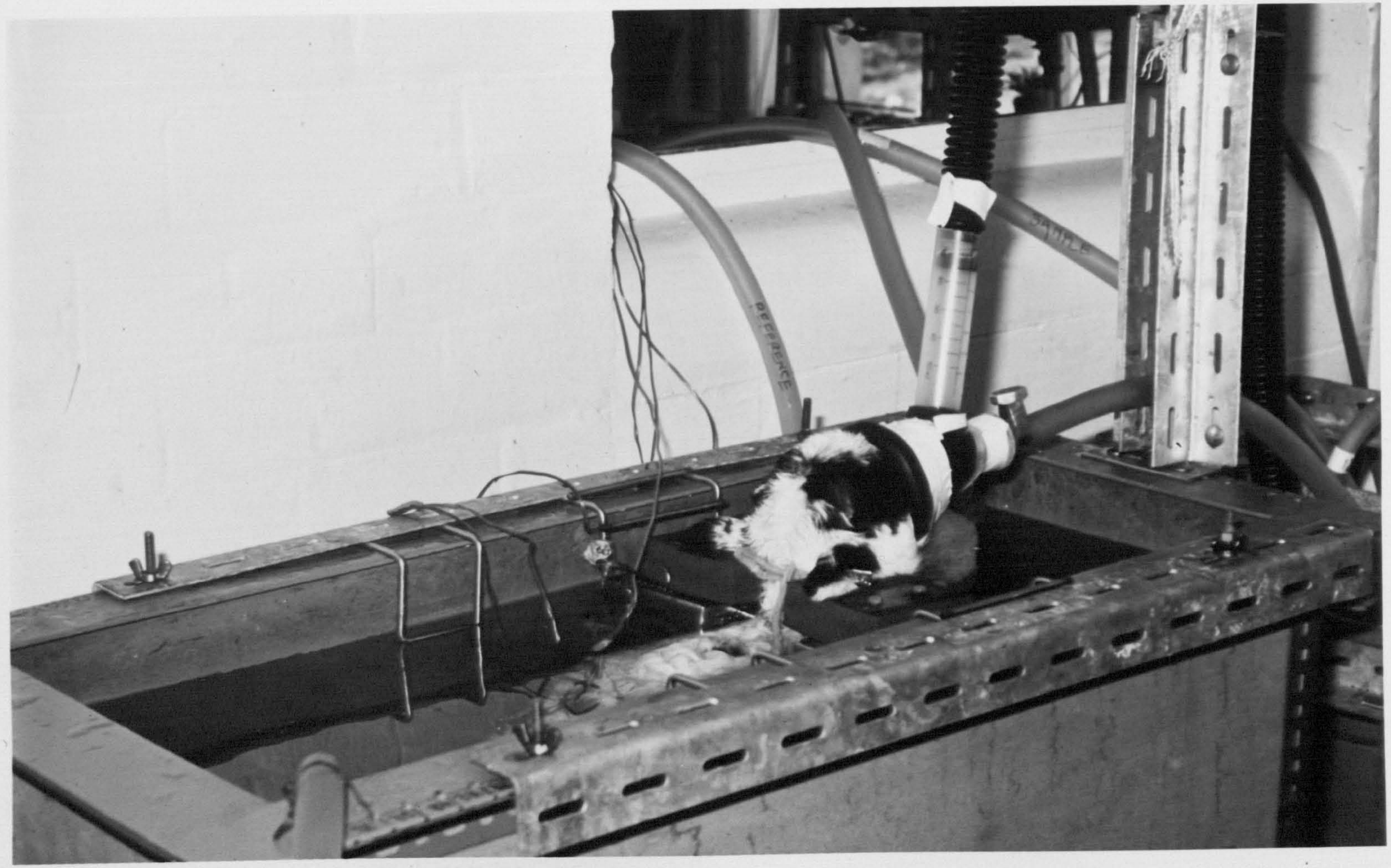


Fig. 6 LAMB WATERBATH IN OPERATION

Edinburgh) from reinforced plastic sheeting clad externally with plyboard and strengthened with an angle iron frame. Water was gravity fed at a set rate from a constant water temperature device consisting of a sensing thermistor controlling hot and cold tap flow through two solenoid valves (see Fig 7). These valves were derived from a domestic automatic washing machine. In trials it was found that water at 15°C (easily obtainable from mixing mains and hot water throughout the lambing season, Dec - June) at a flow rate of one gallon per minute produced a suitable water cooling rate, with bath water temperature falling gradually from thermoneutral levels (38 °C) towards 15 °C over a two hour period. Bath water temperatures were recorded at two depths by thermocouples (Honeywell UK Ltd. Copper Constantan 32 SWG) linked to the data logger. Outlet from the tank was at a higher level than input to allow mixing of the bath water and prevent temperature gradients developing. During trials an electric stirring device was used but this was found to be both unnecessary and a potential hazard. The lamb was held in a leather harness around its hindquarters attached to metal supports. A bar was placed across the back to ensure that it remained below water level. The neck was located in a foam lined rest with care taken not to occlude the trachea etc. The animals were extremely bouyant in the water and appeared very relaxed during thermoneutral exposure. The lamb's rectal temperature was also recorded with a thermocouple probe. Fig 8 shows the standard cooling rate of the waterbath. A check for deviation from this standard was carried out for 125 immersions. Mean deviation from the standard recorded at the end point of each immersion was -1.35 + 0.1 °C and was considered acceptable variation. Careful check was kept on cooling rate during

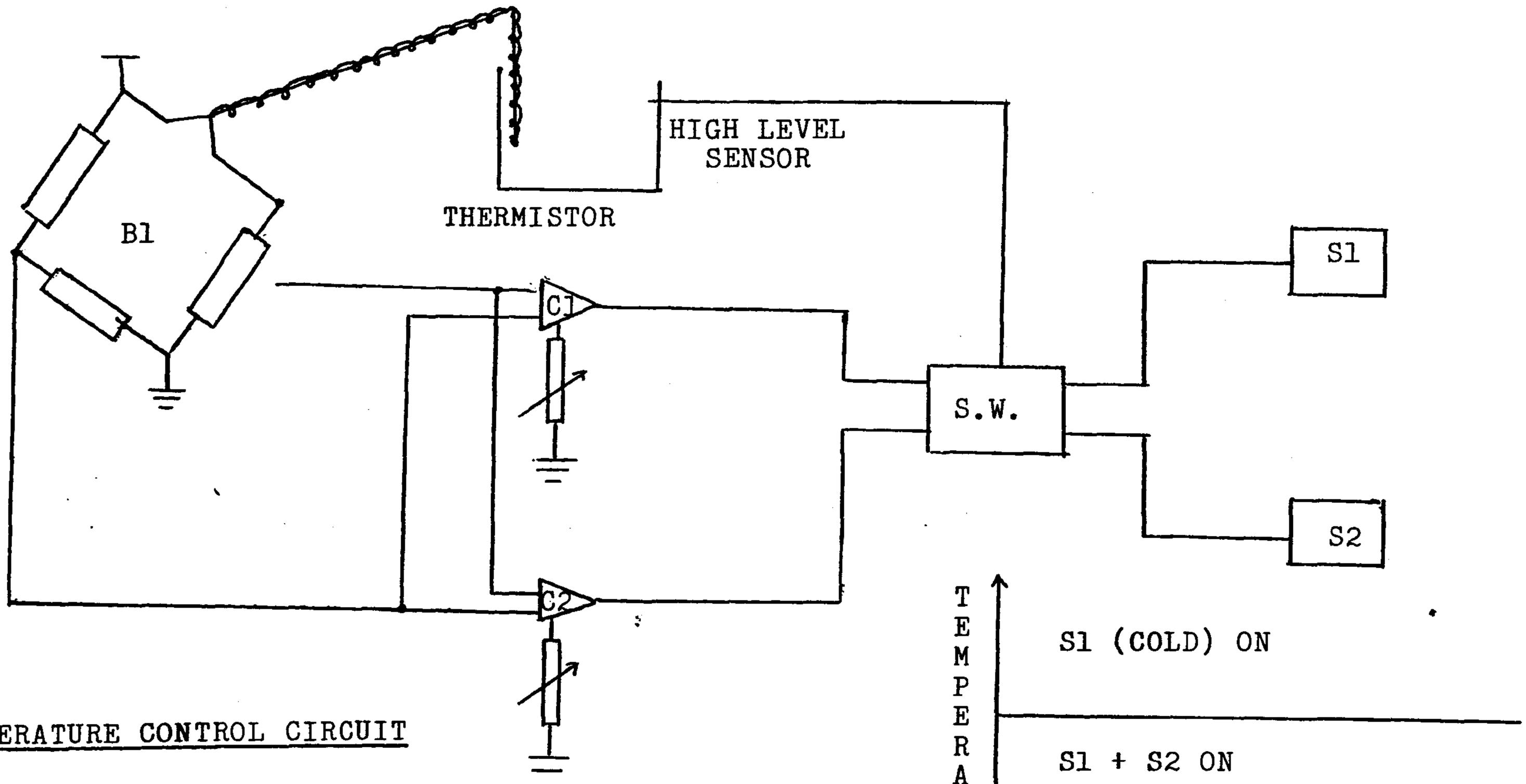


FIG. 7 TEMPERATURE CONTROL CIRCUIT

The circuit was designed to provide a header tank of water that would remain fairly stable in temperature in order to provide a supply of water to the lamb waterbath. The temperature of the water was sensed by a thermistor and the output of the bridge circuit B1 was input to two comparators C1 and C2 with temperature settings just slightly apart. The two setting control potentiometers were interlinked to provide a simple single potentiometer for the control of the output water temperature from the header tank. The outputs of the comparators were input to switching circuitry and output interfaces (SW) such that the off/on switching action followed that of the small graph. Also input to the switching circuit was an input from a sensor indicating that the header tank was full. When this sensor was activated both the solenoid valves (S1 & S2) were deactivated thus preventing overfill of the header tank. This circuit allowed a fairly stable temperature to be maintained in the header tank, any deviation being too small to affect the stability of the temperature in the larger water reservoir being fed.

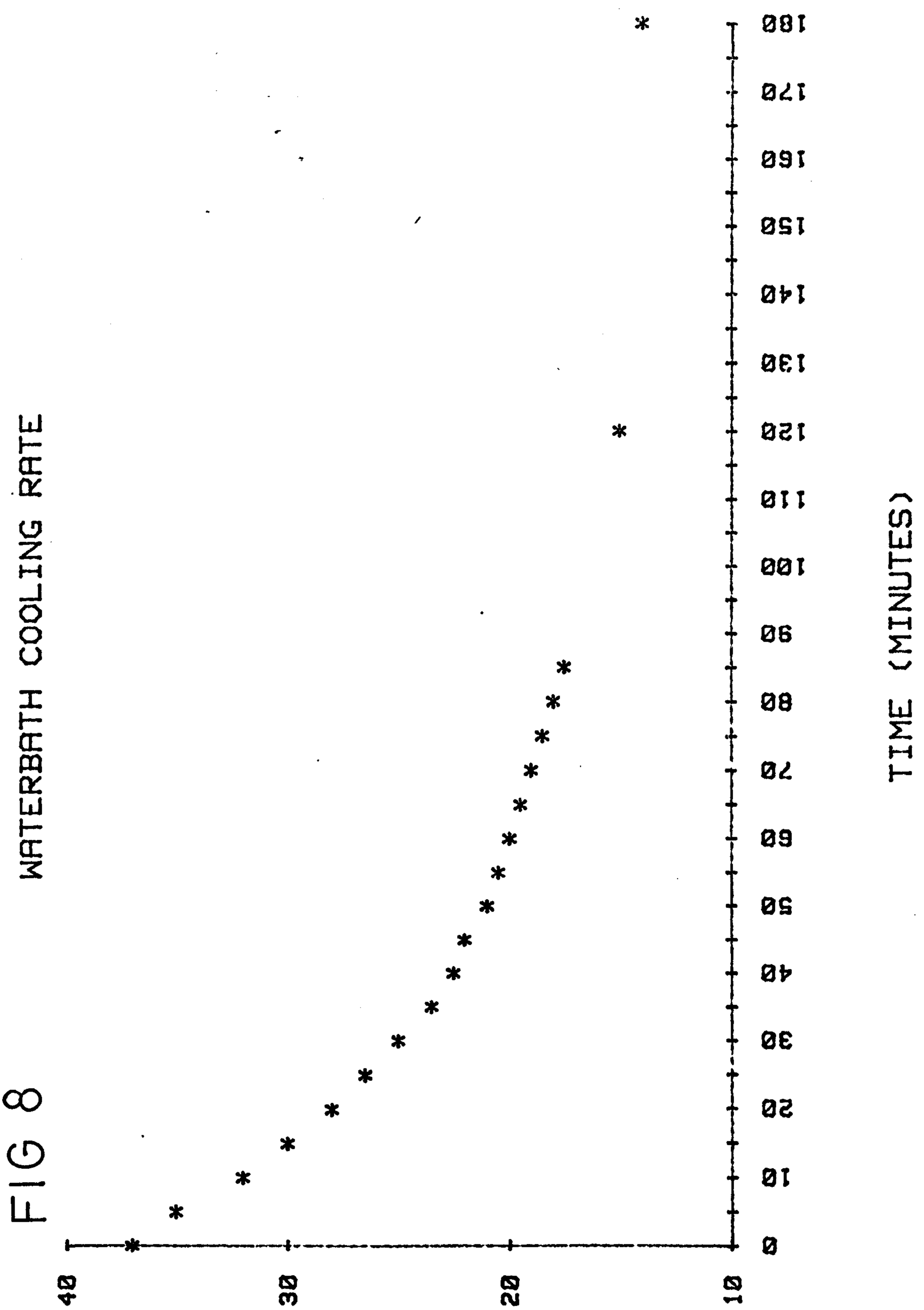


FIG 8
WATER BATH COOLING RATE
WATER TEMPERATURE C
TIME (MINUTES)
40
30
20
10
0
10
20
30
40
50
60
02
08
06
001
011
021
041
061
081

each immersion.

(C) Wind Tunnel Apparatus. (See Slee et al, 1979). The wind tunnel apparatus was designed to allow a cold stress to be applied during which fleece insulation could possibly be expressed more effectively than in the waterbath situation. The equipment is shown in Fig 9. and consists of a wire retaining crate serviced with air supply and exhaust via a face mask, restraints to prevent lying down, and thermocouples to allow measurement of air and rectal temperature. Artificial wind was supplied by a fan at a speed of 6.7m/sec, and artificial rainfall was available at a rate of approximately half a gallon per minute. When used inside the climate chamber a range of air temperatures of +40 ^{o}C to -10 ^{o}C were available. Again a standard test was devised for operation (Slee et al 1979).

(D) Biometry. Analysis of results was done mainly by using a least squares and maximum likelihood analysis of variance package as devised by Harvey (1972). Variables used in analysis are defined and classified as follows:-

Dependent Variables:-

1. Cold Resistance Time - minutes.

2. Final Fall Rate of Rectal Temperature (over last ten minutes of

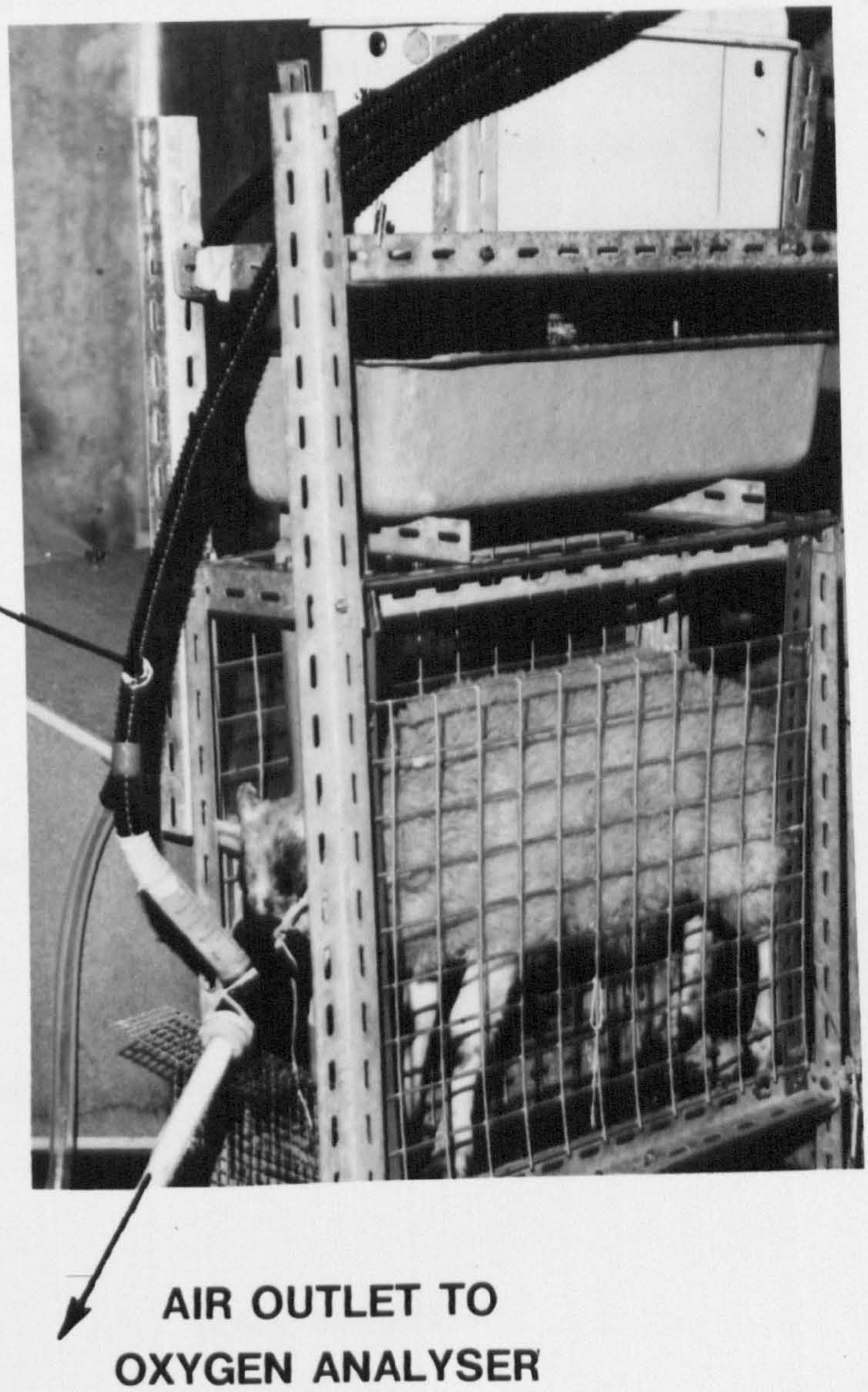


FIG 9 **WIND TUNNEL APPARATUS**

immersion) -^{o}C.

3. Recovery Time - Time to recover rectal temperature to 37^{o}C - minutes.

4. Peak Metabolic Rate - Average of the highest group of ten consecutive minute readings - ml O2/Kgmin.

5. Base Metabolic Rate - Lowest recorded metabolic rate for five consecutive minutes at thermoneutral temperatures - ml02/Kgmin.

6. Last Metabolic Rate - metabolic rate recorded at rectal temperature 35^{o}C - ml02/Kgmin.

7. Time metabolic rate within 5 percent of peak value.

8. Location of PMR from start to cool (minutes).

9. Percentage drop in metabolic rate from peak to last reading.

10. Time from PMR to rectal temperature 35^{o}C (minutes).

Independent Variables:-

1. Skin Thickness - mm - average of five sites.

2. Age - hours.

3. Weight - Kg.

4. Rectal temperature at start to cool.

5. Fleece Depth - cm (midside).

Fixed Effects:-

1. Sex.

2. Littersize.

3. Breed.

4. Fleece Type.

5. Date of Test.

Cold resistance data were adjusted to compensate for the varying degrees of stress imposed due to length of exposure differences between individuals (Samson and Slee, 1981). Data were also log10 transformed to produce a better distribution (see Fig 10).

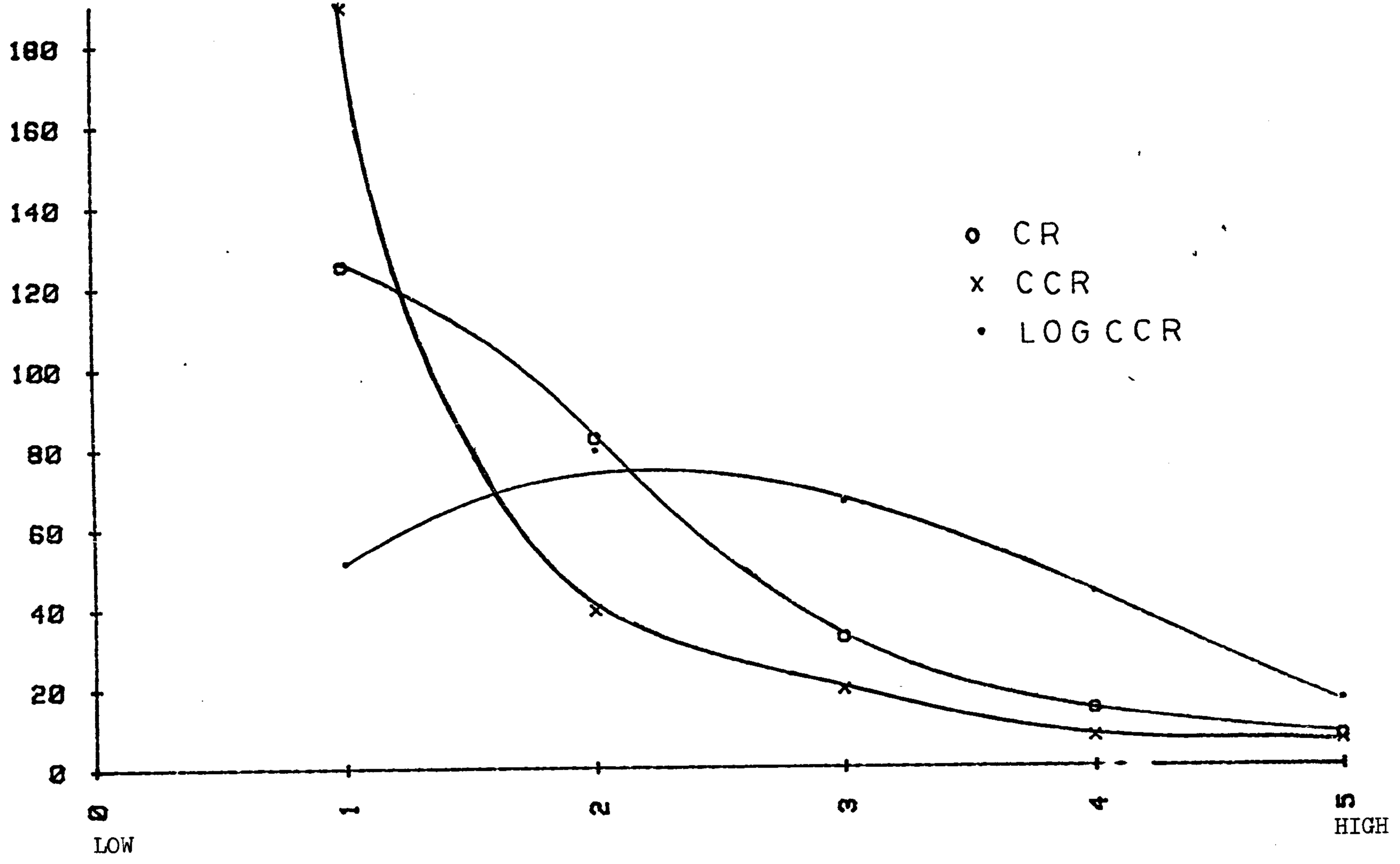
Significance levels of results were recorded up to $p < 0.05$. Outwith this limit differences were considered non-significant (NS). Non-significant variables were dropped from least squares models except where their F ratios were greater than unity.

(E) Animals. The animals used in all experiments were born at ABRO'S Dryden Field Laboratory between 1976 - 1979.

The ten pure breeds used in the main experimentation are illustrated in Fig 11. Lambing was generally out of doors except for Merinos and Finnish Landrace which were, because of their cold susceptibility, almost exclusively lambed indoors, some animals were born indoors at night. Details of flock mortality, rejections from testing and post-test mortality are recorded in Tables A, B, and C (see Appendix 1). All lambs tested were full term and were delivered naturally or with assistance where necessary and returned to their dams after recovery from the test. Subsequent health was closely monitored.

Initially a large percentage of lambs tested were rejected post-test by their dams and a lot of time and effort was spent on adoptive techniques. Several methods were tried to avoid this; bathing both members of a pair of twins, removing both twins together, rubbing lambs in placental fluids pre-return and spraying ewe's nostrils to kill scent detection. Eventually tying the ewes by the neck in a fostering crate for the period the offspring were away,

FIG 10 DISTRIBUTION OF COLD RESISTANCE

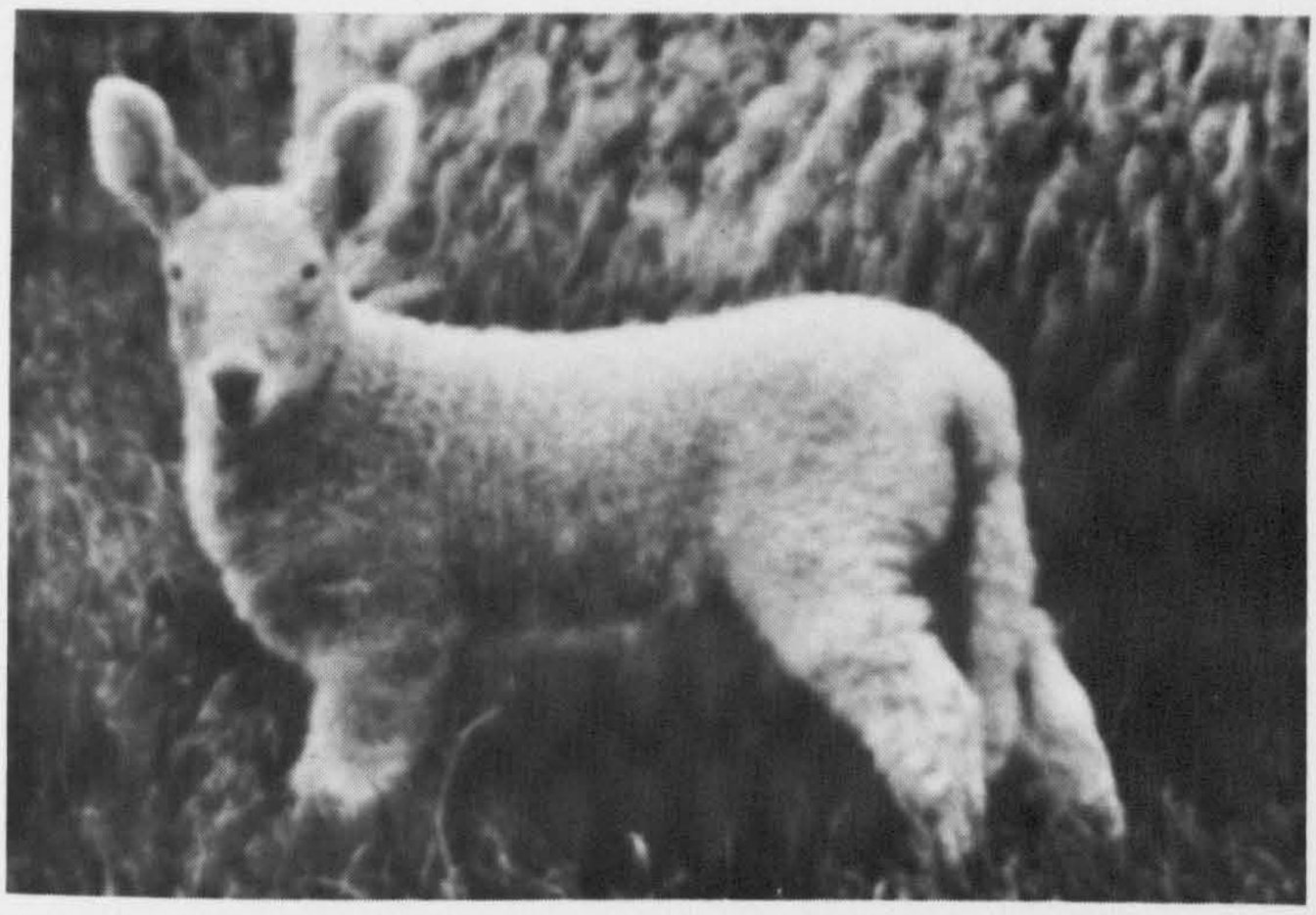


and for the initial period of their return, was found to be almost one hundred percent successful.

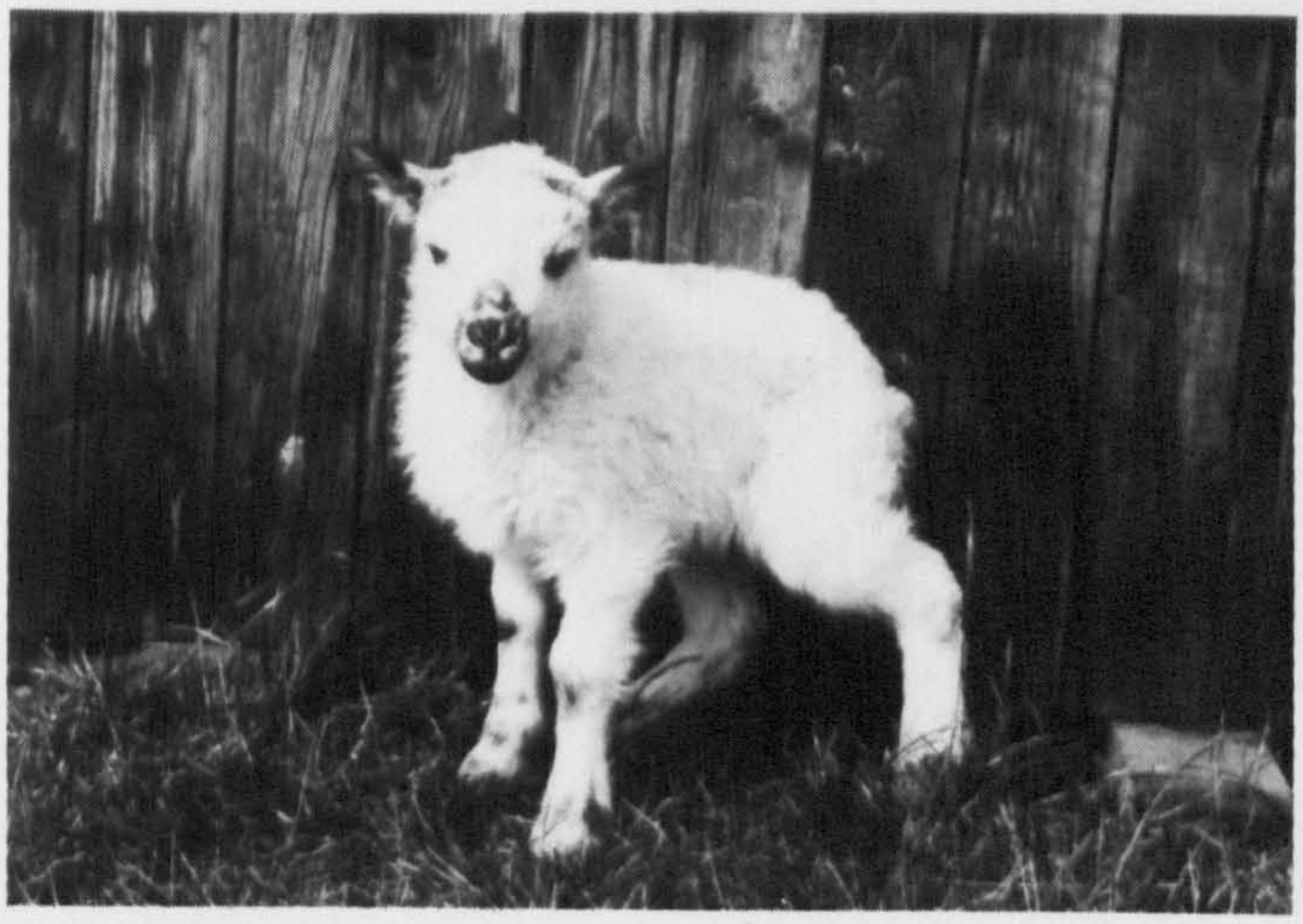
LAMB BREED PHOTOGRAPHS:

Showing variation in birthcoat between and, in some cases, within breeds. With the exception of the Border Leicester and Southdown all lambs shown are less than one week old.

SCOTTISH BLACKFACE



BORDER LEICESTER



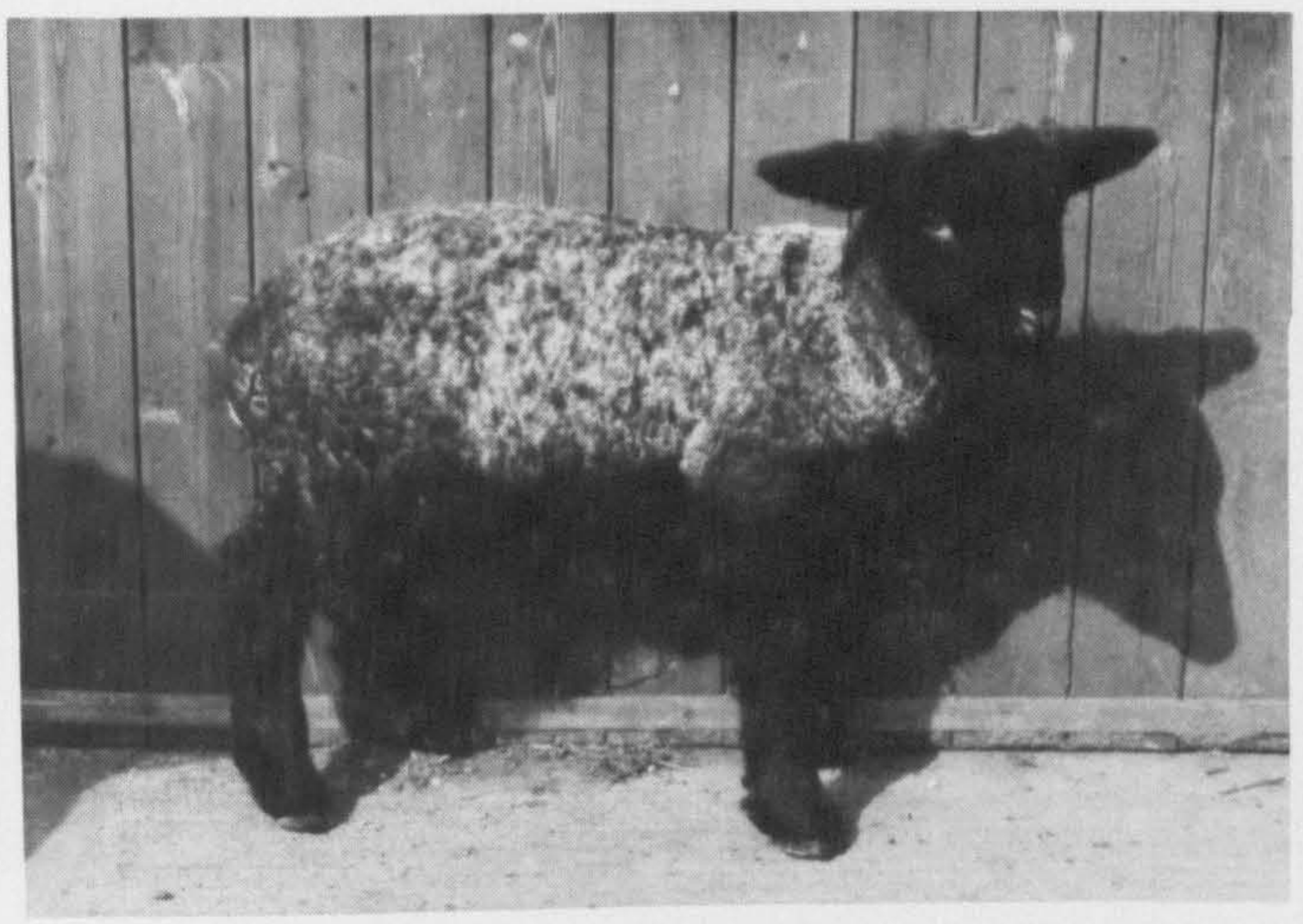
BORERAY BLACKFACE

CHEVIOT

FINNISH LANDRACE (FINE 0.1 mm)

FINNISH LANDRACE (HAIRY 0.8 mm)

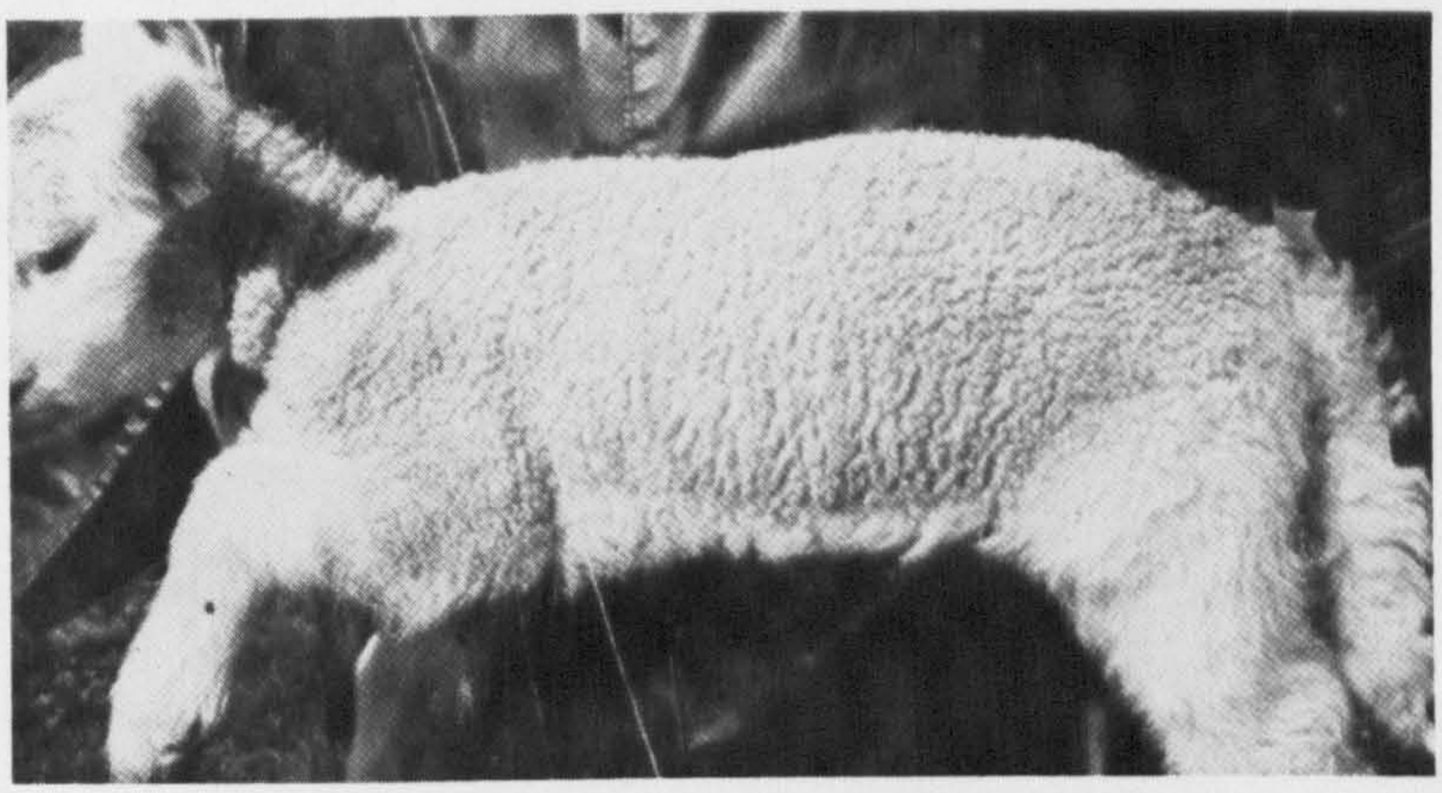
TASMANIAN MERINO



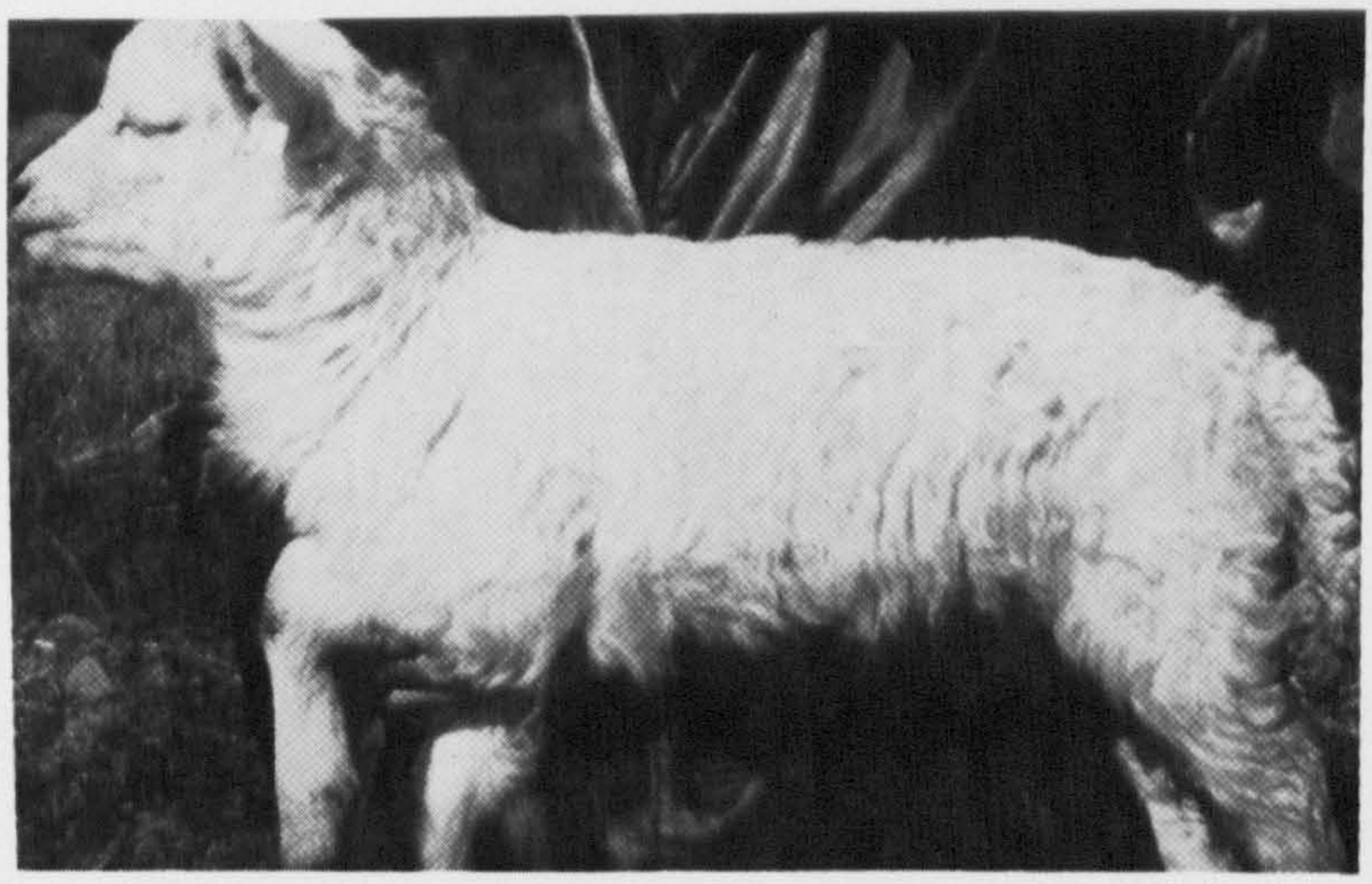
OXFORD DOWN

SOAY

SOUTHDOWN



WELSH MOUNTAIN (FINE)



WELSH MOUNTAIN (HAIRY)

MAIN BREED EXPERIMENT

METHOD.

365 animals of ten pure breeds (Scottish Blackface, Border Leicester, Boreray Blackface, Cheviot, Finnish Landrace, Tasmanian Merino, Oxford, Soay, Southdown, and Welsh Mountain) representing hill, lowland and feral types were used in this experiment. Method for waterbathing was as recorded in Samson and Slee (1981) with the addition of metabolic rate measurements. Upon immersion the lambs were fitted with a face mask incorporated into a respiration calorimetry system as previously described. The lambs were allowed to settle with the water temperature adjusted to thermoneutral levels to allow measurement of a basal metabolic rate. This was estimated when metabolic rate was consistently low over a five minute period. Respiration rates were counted for a number of lambs at this point and rectal temperature was recorded. Water cooling was initiated, usually after about fifteen minutes. The response delay time inherent within the calorimetry system for metabolic rate measurement was only one minute so that a check could be maintained on proceedings by watching the output from the data logger rather than constant supervision within the lamb cabinet which may have disturbed the animal. Oxygen consumption, airflow rate, and air temperature were recorded at minute intervals in conjunction with water and rectal temperature as described in Samson and Slee (1981). Maximum metabolic response was calculated using a computer programme designed to select the group of ten consecutive minute metabolic rate readings giving the largest mean value. Data were prescreened to identify

TABLE 10 MEAN (±SE) AND RANGE OF PHYSICAL CHARACTERISTICS FOR LAMBS USED IN THE MAIN BREED EXPERIMENT

BREED	No. OF LAMBS TESTED	AGE AT TEST (HRS)	WEIGHT AT TEST (Kg)	SKIN FOLD THICKNESS (mm)	PRE-COOLING RECTAL TEMP-ERATURE °C	COAT DEPTH (mm)
Scottish Blackface	33	13.0 ± 2.0	3.7 ± 0.14	4.2 ± 0.08	39.4 ± 0.08	1.8 ± 0.06
Border Leicester	23	23.5 ± 2.4	5.3 ± 0.17	4.1 ± 0.10	39.8 ± 0.09	1.0 ± 0.07
Boreray Blackface	25	20.0 ± 2.3	2.7 ± 0.16	3.6 ± 0.09	39.7 ± 0.09	2.0 ± 0.07
Cheviot	35	17.0 ± 2.0	3.7 ± 0.13	4.1 ± 0.08	39.5 ± 0.07	1.0 ± 0.06
Finnish Landrace	23	19.0 ± 2.4	3.1 ± 0.17	3.0 ± 0.10	39.1 ± 0.09	0.7 ± 0.07
Tasmanian Merino	21	18.0 ± 2.6	3.7 ± 0.17	3.1 ± 0.10	39.5 ± 0.10	0.5 ± 0.07
Oxford Down	20	20.0 ± 2.6	5.8 ± 0.18	4.1 ± 0.10	39.7 ± 0.10	0.9 ± 0.07
Soay	38	21.0 ± 1.9	2.2 ± 0.13	3.1 ± 0.10	39.4 ± 0.09	1.7 ± 0.05
Southdown	26	21.0 ± 2.3	3.9 ± 0.16	3.7 ± 0.09	39.8 ± 0.07	0.6 ± 0.06
Welsh Mountain	21	21.0 ± 2.5	3.4 ± 0.17	4.3 ± 0.10	39.6 ± 0.10	1.6 ± 0.07
Total/Mean	265	19.0 ± 0.7	3.6 ± 0.05	3.7 ± 0.04	39.6 ± 0.03	1.2 ± 0.02
Range		0.5 -60.0	1.4 - 8.8	2.2 - 5.4	37.9 -40.6	0.3 - 2.9
Significance of Variation between Breeds		NS	P < .001	P < .001	P < .001	P < .001

outliers caused by technical problems. Peak metabolism was alternatively calculated by taking the average of all the readings within 5 percent of the absolute maximum. Other programmes were developed to locate the metabolic and cold resistance variables for analyses as listed in the Biometry section. Five lambs were held as experimental controls at thermoneutral temperatures in the water bath with no cooling regime operating.

The waterbathing technique was more extensively investigated in an experiment described in Appendix 2. Here an attempt was made to estimate the contribution of the respiratory heat loss component whilst monitoring tidal volume changes during cooling.

RESULTS

(i) Physical Characteristics. Physical data are shown in Table 10. Significant breed variation was recorded for weight, skin thickness ("Harpenden" dial callipers), initial rectal temperature and coat depth. A range of ages was tested (0.5 -60 hours) but no significant between breed age variation was imposed on the experiment. Birthcoat variations can be seen in Fig 11. Fleece depth together with fleece type, graded hairy to fine on a six point scale (Ryder, 1974) were both fitted in preliminary ANOVA models. Birthcoat characteristics were not included in final analyses of metabolic rate and cold resistance as no significant effects were found, despite much breed variation in fleece depth and wool weight. Presumably the wetting of the fleece negated it's insulative properties.

Rectal temperature recorded whilst the animal was held

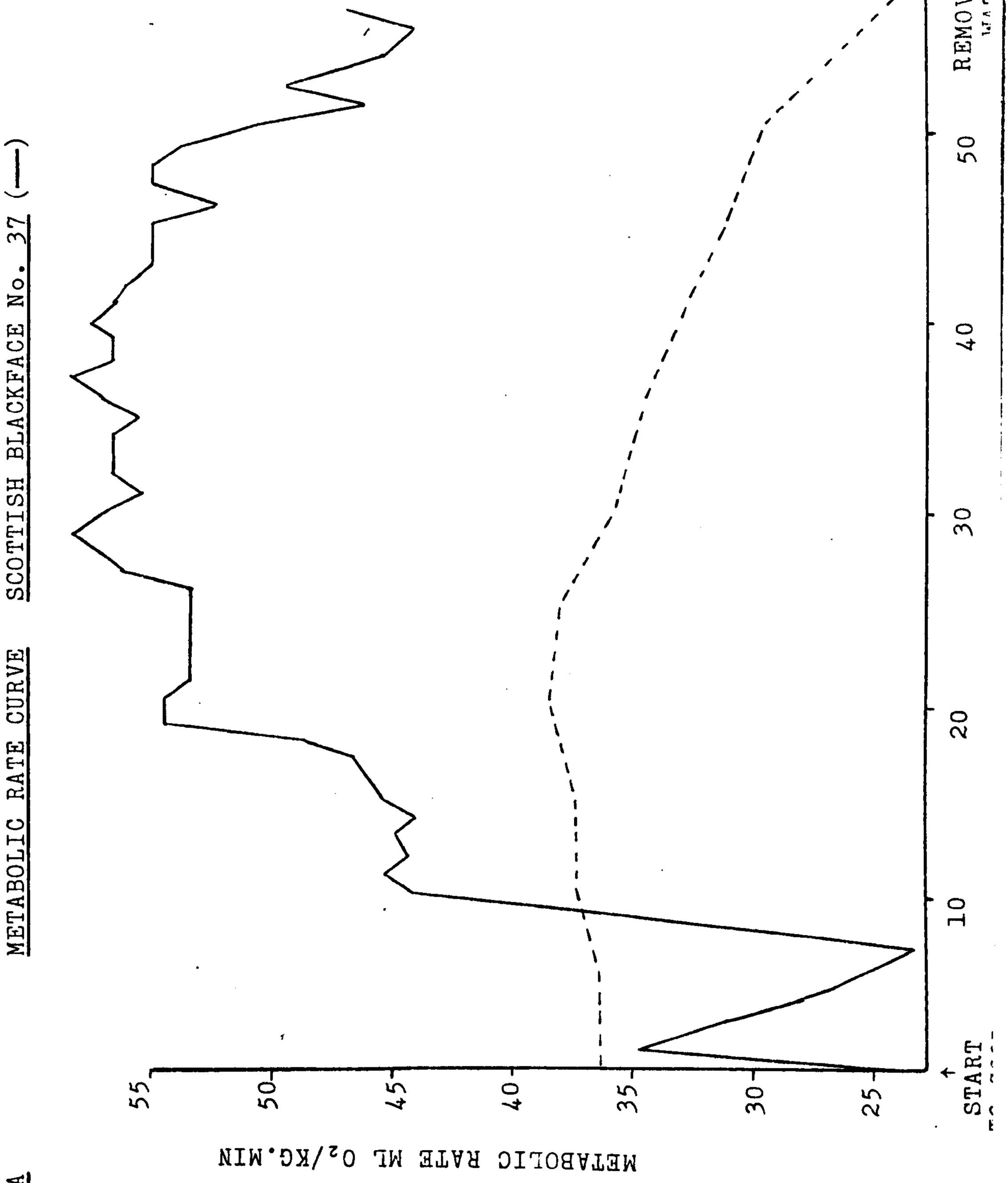
TABLE 10A WITHIN BREED VARIATION FOR PHYSICAL CHARACTERISTICS

BREED	WEIGHT (Kg)	SKIN THICKNESS (MM)	AGE (HRS)	INITIAL RECTAL TEMP.(°C)	FLEECE DEPTH (CM)
Scottish Blackface	2.45 - 5.1	3.5 - 4.9	0.5 - 29	37.9 - 40.1	1.3 - 2.5
Border Leicester	4.3 - 8.8	2.8 - 5.1	4 - 42	38.9 - 40.6	0.6 - 1.6
Boreray Blackface	1.6 - 3.8	2.8 - 4.2	1.25 - 44	39.3 - 40.4	1.2 - 2.9
Cheviot	2.5 - 5.15	3.0 - 5.3	2 - 45	38.4 - 40.5	0.5 - 1.8
Finnish Landrace	2.0 - 4.45	2.4 - 3.9	4 - 48	38.2 - 39.9	0.3 - 1.2
Tasmanian Merino	2.1 - 4.9	2.2 - 3.9	3 - 45	38.9 - 40.5	0.3 - 0.9
Oxford	3.0 - 7.8	3.0 - 5.4	3.25 - 44	39.0 - 40.5	0.4 - 1.2
Soay	1.4 - 3.0	2.5 - 3.8	1.5 - 60	38.7 - 40.2	1.0 - 2.3
Southdown	2.5 - 4.8	3.0 - 5.3	5 - 40.5	39.2 - 40.5	0.3 - 0.9
Welsh Mountain	2.3 - 4.45	3.6 - 5.2	5 - 54	38.8 - 40.2	0.7 - 2.5

immediately prior to immersion was also examined. This parameter proved unsuitable as individual variations, presumably as a result of handling stress, made it a very variable parameter and it's use was superseded by "initial rectal temperature," ie rectal temperature recorded after a period at thermoneutral temperatures in the water bath.

The lambs comprised 130 males and 135 females , of which there were 107 singles, 136 twins, and 22 triplets. Not all lambs from each litter were bathed but this was done as often as possible to alleviate subsequent problems of mothering up. Within breed variation is shown in Table 10A.

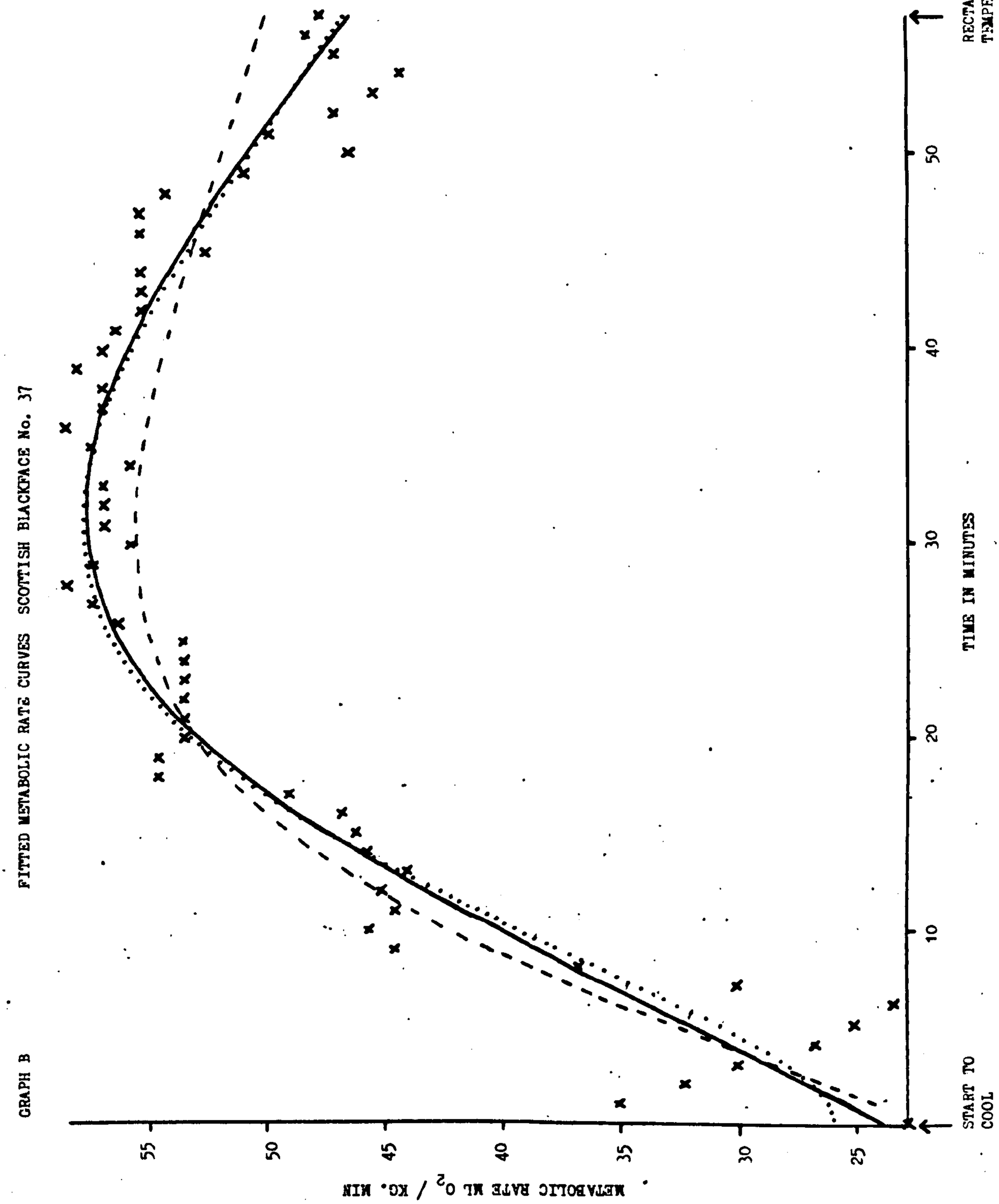
(ii) Metabolic Rate. A typical metabolic response to cooling is shown in Graph A. After an initial steady period during which base metabolism is estimated, "start to cool" is characterised by a sudden increase in oxygen consumption probably associated with the activity of personnel/equipment in initiating the drop in water temperature. The animal then settles down until water cooling has an effect on the peripheral skin temperature receptors. Metabolic rate increases steadily towards a maximum after which it plateaus out, (No such response pattern emerged for the control lambs, metabolic rate did not significantly exceed base levels except for brief periods throughout these immersions). This plateau eventually changes into a rapid decline. Rectal temperature rises initially after cooling starts and then starts to fall as maximal metabolic effort is approached, so that rectal temperature generally is just beginning to drop as maximum metabolism is expressed. This temperature rise, when it occurred, was generally less than one degree centigrade and was


RECTAL TEMPERATURE °C (— —)
40
39
38
37
36
35
34
REMOVED FROM
50
40
30
20
10
START
SCOTTISH BLACKFACE No. 37 (——)
METABOLIC RATE CURVE
55
50
45
40
35
30
25
METABOLIC RATE ML O2/KG.MIN

GRAPH A

not analysed further as it was thought the temperature sensing and recording equipment was not accurate enough to allow comparison of such small transient differences. Rectal temperature at peak metabolic rate was analysed for 248 lambs. The mean value was 39.04 $\pm$ 0.06 with a range 36.0 to 40.9 ^{o}C. Breed differences were not significant.

Metabolic rate was plotted at minute intervals, variation can be observed between consecutive readings. A pattern of high following low is often discernible. Some of this variation may be as a result of the animal's respiratory cycle and some of the larger variations as a result of muscular activity with associated periods of breath holding. Careful note was taken of the effects of activity although it was not a common occurrence during immersion. Two lambs were excluded from analysis for this reason. It was easy to eliminate periods of muscular activity from data sets as these were generally brief (two minutes) and associated metabolic rates were far in excess of the surrounding data. The data were screened to trap such variation. Vigorous struggling is often followed immediately by a drop in rectal temperature greater than the general trend, probably as the heat produced by muscular activity is efficiently carried away by convective currents set up as thermal gradients in the water are disturbed. Graph B (same data as Graph A) shows an attempt to express the metabolic response to cold mathematically by fitting known curves. Three different curves were fitted in an attempt to rationalise the physiological response for comparative purposes. No clear pattern emerged in this obviously complex physiological response. Successive readings showed correlations of about 0.5 although there was great variation between individuals. If the


FITTED METABOLIC RATE CURVES SCOTTISH BLACKFACE No. 37
GRAPH B
METABOLIC RATE ML O_2 / KG. MIN
55
50
45
40
35
30
25
TIME IN MINUTES
10
20
30
40
50
START TO COOL
RECTAL TEMPERATURE AT 35°C

metabolic rate is high on one occasion, it is likely to be high on the next. This is probably a function of too small an interval between measurements. Variability is greatest for the initial part of the curve.

Raw data for breed mean, peak and base metabolic rate are given in Tables 11, 11A. Both definitions of PMR are recorded, in practice there is less than 1 percent difference in their mean estimations but the average of the top ten consecutive minutes is preferred as this is less likely to be limited by rectal temperature as the 5 percent levels can in some instances encompass over 60 minutes of consecutive readings during which rectal temperature may have dropped below 37°C. The definition of PMR as an average of readings within the 5 percent limits of absolute peak was based on maximum levels of error likely to be inherent in measurement of flow rate, oxygen consumption, weight, and subsequent rounding errors during recording, printing and calculating. The former definition was used in all subsequent analyses.

Repeatability of peak metabolic rate estimations within individuals (n=18) with a minimal 24 hour interval between estimations was 0.64 ($p < 0.01$).

Tables 11, 11A show significant breed variation in peak and base metabolic rate raw data with metabolic rate expressed per unit weight (11) and without the weight term (11A). Graph C shows the relationship between PMR and BMR and weight across all the breeds and Graph D shows a comparison between breeds. Major visual differences can be seen between breeds of different weights, for example Soay compared with Oxford and Border Leicester; the larger breeds having the highest oxygen consumption. Data are plotted using a double log

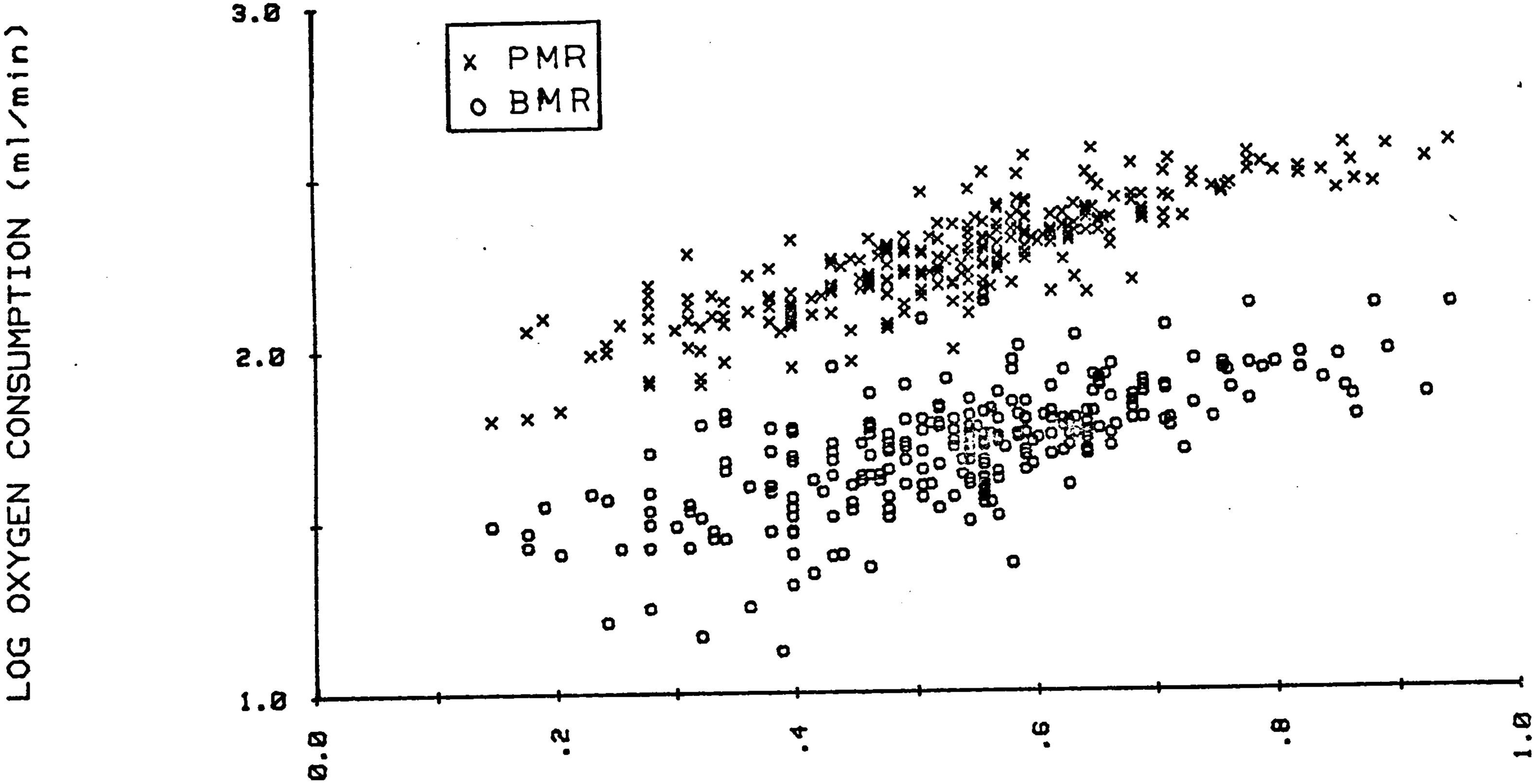
TABLE 11 BREED MEANS (± SE) FOR PEAK AND BASE METABOLIC RATE PER UNIT BODY WEIGHT (UNADJUSTED DATA)

BREED	n	1. PEAK METABOLIC RATE (ml O_2/Kg min) AVERAGE OF TOP TEN CONSECUTIVE READINGS	2. PEAK METABOLIC RATE (ml O_2/Kg min) AVERAGE OF ALL VALUES WITHIN 5% LIMITS OF ABSOLUTE MAXIMUM	PERCENTAGE DIFFERENCE BETWEEN 1. AND 2.	BASE METABOLIC RATE (ml O_2/Kg min)
Scottish Blackface	33	51.68 ± 1.79	52.08 ± 1.59	-0.78	13.59 ± 0.75
Border Leicester	23	47.28 ± 2.14	48.44 ± 1.91	-2.4	14.69 ± 0.90
Boreray Blackface	25	59.73 ± 2.06	59.64 ± 1.82	+0.02	15.40 ± 0.86
Cheviot	35	60.91 ± 1.74	61.18 ± 1.54	-1.6	13.39 ± 0.73
Finnish Landrace	23	54.68 ± 2.14	53.57 ± 1.91	+2.1	20.04 ± 0.90
Tasmanian Merino	21	52.45 ± 2.24	52.47 ± 1.99	0	15.33 ± 0.94
Oxford Down	21	49.58 ± 2.30	50.55 ± 2.04	-1.92	14.51 ± 0.96
Soay	38	56.75 ± 1.67	57.45 ± 1.48	-1.22	18.47 ± 0.70
Southdown	26	54.52 ± 2.02	57.34 ± 1.79	-4.9	15.44 ± 0.84
Welsh Mountain	21	58.82 ± 2.24	57.56 ± 1.99	+2.1	15.79 ± 0.94
Mean	265	55.01 ± 0.67	55.44 ± 0.44	-0.78	15.65 ± 0.29
Range		18.21 - 94.25	20.96 - 91.95		5.5 - 38.5
SIGNIFICANCE OF VARIATION BETWEEN BREEDS		P < 0.001	P < 0.001		P < 0.001

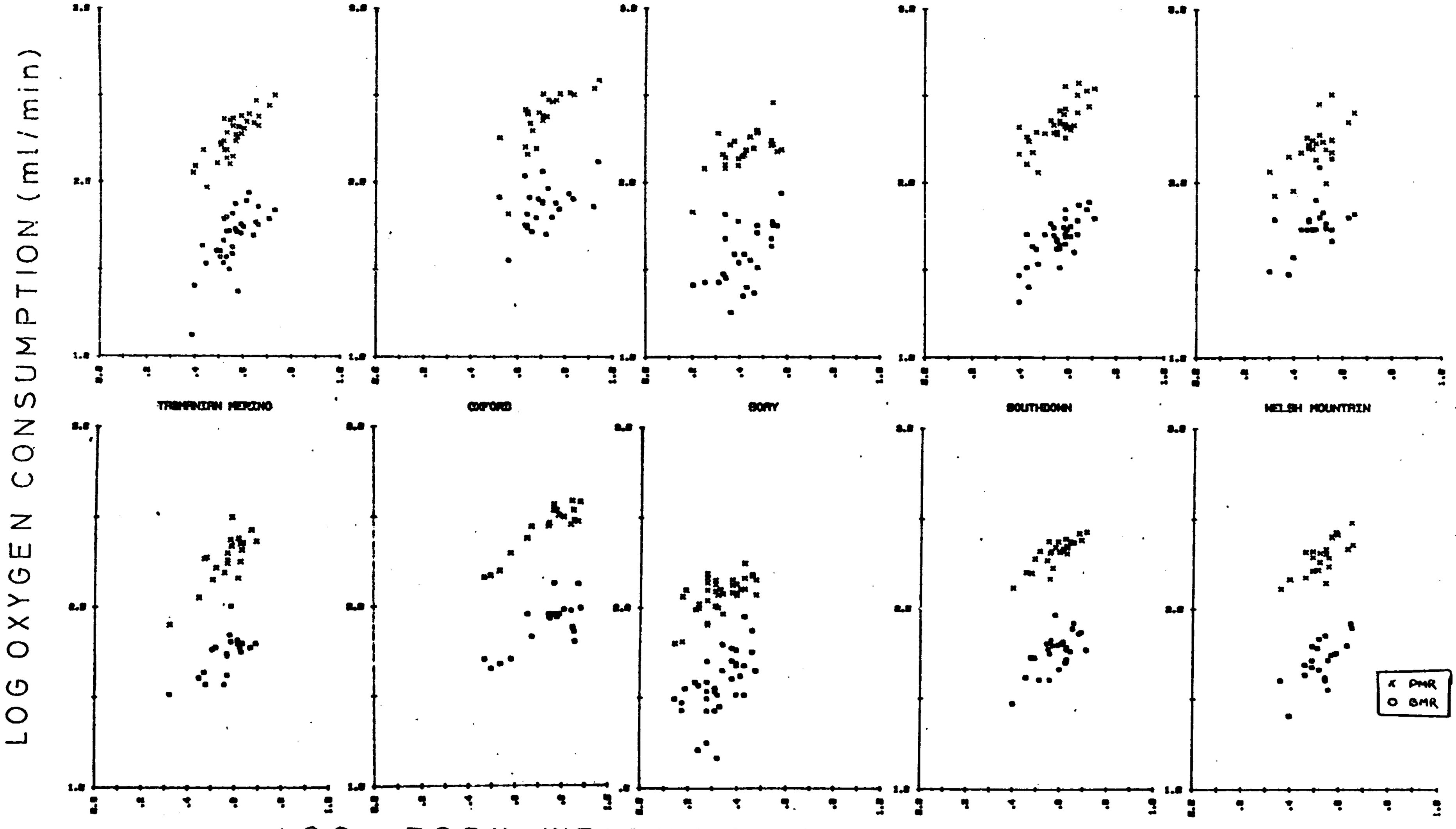
TABLE 11A BREED MEANS (±SE) FOR PEAK AND BASE METABOLIC RATES (UNADJUSTED DATA)

BREED	n	PEAK METABOLIC RATE (ml O_2/min)	BASE METABOLIC RATE (ml O_2/min)
Scottish Blackface	33	184.59 ± 9.14	47.44 ± 3.16
Border Leicester	23	236.43 ± 18.84	72.71 ± 4.42
Boreray Blackface	25	155.06 ± 8.03	38.73 ± 3.11
Cheviot	35	217.62 ± 9.92	47.74 ± 2.35
Finnish Landrace	23	162.03 ± 11.04	58.37 ± 4.17
Tasmanian Merino	21	188.63 ± 12.60	55.11 ± 3.16
Oxford Down	20	273.53 ± 18.33	78.96 ± 5.40
Soay	38	119.51 ± 4.40	37.83 ± 2.33
Southdown	26	208.55 ± 7.39	58.34 ± 2.83
Welsh Mountain	21	197.29 ± 9.72	52.41 ± 3.21
Mean	265	184.93 ± 4.09	51.53 ± 1.25
Range		63.83 - 386.37	13.49 - 138.04
Significance of Variation between Breeds		P < 0.001	P < 0.001

GRAPH C RELATION OF SUMMIT AND BASAL METABOLIC RATE TO BODY WEIGHT IN 265 LAMBS AGED 0-5 - 60 HRS.



GRAPH D RELATION OF METABOLIC RATE TO BODY WEIGHT FOR 10 BREEDS OF LAMBS



plot in order to improve the distribution of metabolic rate data towards the normal. Regression lines were not fitted at this stage as the data were further analysed in a least squares programme (Harvey, 1972). The model fitted for PMR is shown in Table 12. Breed differences present in the raw data are seen to be largely a function of weight ($p < 0.001$). Day of test also has a significant ($p < 0.001$) effect on PMR. Females show significantly larger ($p < 0.02$) PMR than males, the age regression is positive and significant ($p < 0.02$) older animals showing higher PMR. Regression with initial rectal temperature is positive and significant ($p < 0.02$). Breed and skin thickness do not have significant effects but are included in the model as F ratios are greater than one.

The constant estimate derived for the regression of weight on PMR within the model is 0.982 ± 0.104, thus this relationship is to all purposes, unity, and PMR is directly related to body weight rather than some function of weight such as surface area.

Peak metabolic rate was also analysed when expressed per unit weight. Graph E shows this relationship for raw data; again regressions were not fitted at this stage as the data were further analysed by least squares ANOVA. The ANOVA model and results are shown in Table 13. Here again there are no significant breed effects, all other variables conform to the previous analysis except for weight which is dropped from the model as it has no significant effect (F ratio = 0.04) being already incorporated in the metabolic rate term.

Base metabolic rate was analysed in the same way. Table 14 gives least squares analysis of data. No significant breed differences are recorded but weight again has a highly significant

TABLE 12 LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING PEAK METABOLIC RATE

VARIABLE	DF	MEAN SQUARE	F.RATIO	SIGNIFICANCE LEVEL
Breed	9	0.0071	1.54	NS
Day of Test	137	0.0077	1.67	P < 0.001
Sex	1	0.0236	5.10	P < 0.02
Litter Size	2	0.0102	2.22	NS
Skin Thickness	1	0.0075	1.62	NS
Weight	1	0.4102	88.79	P < 0.001
Age	1	0.0183	3.96	P < 0.02
Initial Rectal Temp.	1	0.0240	5.20	P < 0.02
Remainder	111	0.0046		

GRAPH E

RELATION OF SUMMIT METABOLIC RATE PER UNIT BODY WEIGHT TO BODY WEIGHT IN 265 LAMBS OF 10 BREEDS

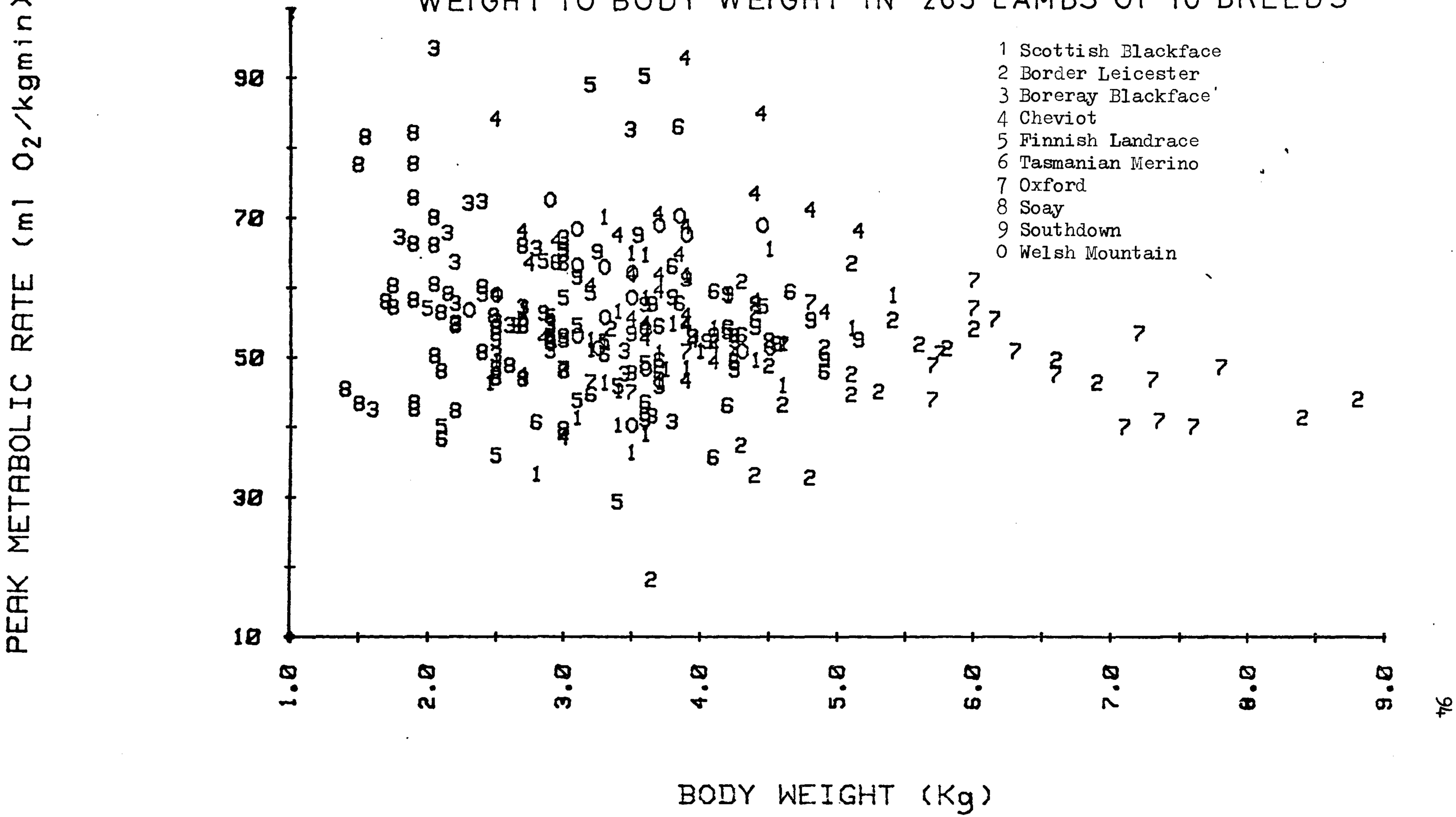


TABLE 13 LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING PEAK METABOLIC RATE PER UNIT WEIGHT

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE LEVEL
Breed	9	0.0071	1.57	NS
Day of Test	137	0.0077	1.69	$P < 0.001$
Sex	1	0.0271	5.99	$P < 0.02$
Litter Size	2	0.0110	2.44	NS
Skin Thickness	1	0.0077	1.71	NS
Age	1	0.0182	4.02	$P < 0.02$
Initial Rectal Temp.	1	0.0236	5.21	$P < 0.02$
Remainder	112	0.0045		

TABLE 14 LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING BASE METABOLIC RATE

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE LEVEL
Breed	9	0.0145	1.62	NS
Day of Test	137	0.0158	1.77	$P < 0.001$
Weight	1	0.4175	46.86	$P < 0.001$
Initial Rectal Temp.	1	0.1702	19.11	$P < 0.001$
Remainder	116	0.0089		

effect. The constant estimate with weight was 0.824 ± 0.120, again not significantly different from unity. The effect of initial rectal temperature was also significant. Age, sex, skin thickness and litter size had no significant effect. Table 15 gives the analysis of variance for base metabolic rate per unit weight; here breed does have a significant effect. Least squares breed means are shown in Table 16. Table 15A shows results of BMR/Kg with weight in the model, unlike PMR/Kg, weight shows some effect on the variation but not a significant one. The inclusion of weight however makes breed effects non-significant. Least squares means generated from this model are shown in Table 16A. Raw data for BMR per unit weight is plotted in Graph F.

Respiration rate was counted for 112 animals during BMR estimations; the mean value was 58 ± 1.27 respirations per minute, with a range of 35 - 107.

Other metabolic rate related variables were analysed. The results are in Tables 17 and 18.

The metabolic rate recorded at 35°C rectal temperature just prior to removal from the waterbath (Table 17) showed no significant breed variation. Values for individual lambs ranged 15.2 - 75.0 with a mean of 46.04 ±0.53. Main significant variables were: day of test, sex (female higher than male), age (positive correlation), and initial rectal temperature (positive correlation). Skin thickness and day of test significantly affected the location of PMR in the cooling schedule (Table 18).

The average percentage drop between PMR and metabolic rate at rectal temperature 35°C was 15.5 ± 0.46 percent. There was no significant variation with breed, day of test being the only

TABLE 15. LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING BASE METABOLIC RATE PER UNIT WEIGHT (EXCLUDING WEIGHT)

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE LEVEL
Breed	9	0.02188	2.43	$P < 0.02$
Day of Test	137	0.0157	1.75	$P < 0.001$
Initial Rectal Temp.	1	0.1584	17.61	$P < 0.001$
Remainder	117	0.0090		

TABLE 15A LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING BASE METABOLIC RATE PER UNIT WEIGHT (INCLUDING WEIGHT)

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE LEVEL
Breed	9	0.0145	1.62	NS
Day of Test	137	0.0158	1.77	$P < 0.001$
Weight	1	0.0193	2.17	NS
Initial Rectal Temp.	1	0.1698	19.06	$P < 0.001$
Remainder	116	0.0089		

TABLE 16 LEAST SQUARES BREED MEANS (±SE) FOR PEAK AND BASE METABOLIC RATES PER UNIT WEIGHT (WEIGHT EXCLUDED FROM BMR MODEL)

	PMR (ml O_2/Kg min)	BMR (ml O_2/Kg min)
Scottish Blackface	49.17 ± 3.82	14.19 ± 1.38
Border Leicester	43.97 ± 3.59	11.28 ± 1.12
Boreray Blackface	62.13 ± 8.83	16.65 ± 3.22
Cheviot	53.15 ± 3.38	13.97 ± 1.12
Finnish Landrace	51.13 ± 6.09	20.16 ± 2.34
Tasmanian Merino	49.49 ± 4.24	15.04 ± 1.46
Oxford Down	65.33 ± 6.86	13.05 ± 1.88
Soay	49.79 ± 3.98	16.48 ± 1.48
Southdown	49.83 ± 3.29	15.66 ± 1.37
Welsh Mountain	52.12 ± 3.71	15.00 ± 1.29

TABLE 16A LEAST SQUARES BREED MEANS (± SE) FOR BASE METABOLIC RATE (WITH WEIGHT IN MODEL)

	BMR (ml O_2/Kg min)
Scottish Blackface	14.25 ± 1.38
Border Leicester	12.13 ± 1.32
Boreray Blackface	15.28 ± 3.09
Cheviot	14.46 ± 1.19
Finnish Landrace	20.15 ± 2.33
Tasmanian Merino	14.95 ± 1.45
Oxford Down	14.47 ± 2.29
Soay	14.83 ± 1.73
Southdown	16.17 ± 1.44
Welsh Mountain	15.26 ± 1.31

GRAPH F RELATION OF BASE METABOLIC RATE PER UNIT BODY WEIGHT TO BODY WEIGHT IN 265 LAMBS OF 10 BREEDS

1 Scottish Blackface
2 Border Leicester
3 Boreray Blackface
4 Cheviot
5 Finnish Landrace
6 Tasmanian Merino
7 Oxford
8 Soay
9 Southdown
0 Welsh Mountain

BASE METABOLIC RATE (ml O_2/kgmin)

35
25
15
5

1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0

BODY WEIGHT (Kg)

TABLE 17 LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING METABOLIC RATE AT 35°C

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE LEVEL
Breed	9	0.0070	1.29	NS
Day of Test	137	0.0071	1.32	$P < 0.02$
Sex	1	0.0254	4.69	$P < 0.02$
Litter size	2	0.0159	2.94	NS
Age	1	0.0324	5.97	$P < 0.02$
Initial rectal temperature	1	0.0299	5.52	$P < 0.02$
Remainder	113	0.0054		

TABLE 18 LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING THE TIME (MINS.) PMR OCCURS AFTER COOLING IS INITIATED.

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE LEVEL
Breed	9	238.96	1.93	NS
Dayof Test	137	154.24	1.25	$P < 0.02$
Skin Thickness	1	723.27	5.85	$P < 0.02$
Weight	1	141.12	1.14	NS
Age	1	223.52	1.81	NS
Remainder	115	123.67		

significant affecting factor ($p < 0.001$). Analysis was also carried out on the time 5 percent of the peak metabolic rate was held. Presumably ability to maintain high metabolic rate may have importance in cold survival. No significant breed or day of test variation was recorded but skin thickness has a significant effect ($p < 0.001$).

(iii) Cold Resistance. Results for cold resistance are shown in Tables 2, 3, 5, in Samson and Slee (1981) (bound at end).

Further analysis of the data identified other significant factors influencing resistance to body cooling including litter size (with weight effects taken out), with triplets more resistant than twins who are more resistant than singles. Initial rectal temperature is also important, but this may only be as a result of a greater rectal temperature difference between that recorded at base estimations and 35°C for lambs with higher initial temperatures; or the lambs with higher rectal temperatures after adjustment for breed effects may reflect better potential homeothermic capability. Day of test is also significant.

In addition to these results the variable defined as the time taken for rectal temperature to drop from that associated with peak metabolic rate to rectal temperature 35 °C was analysed (Table 19). Breed variation was significant ($p < 0.01$). Least squares means are shown in Table 20.

The final rate of rectal temperature fall during the last ten minutes prior to rectal temperature 35°C was also analysed. Breed differences (Table 22) were recorded in a least squares model (Table 21) with weight and age having significant effects, with larger and

TABLE 19 LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING TIME (MINUTES) FROM PMR TO RECTAL AT 35°C.

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE LEVEL
Breed	9	691.61	2.83	P < 0.01
Day of Test	137	348.55	1.43	P < 0.02
Sex	1	849.56	3.47	NS
Litter size	2	704.36	2.88	NS
Skin Thickness	1	881.61	3.60	NS
Weight	1	939.05	3.84	NS
Age	1	295.75	1.21	NS
Initial rectal temperature	1	1081.12	4.42	P < 0.02
Remainder	111	244.66		

TABLE 20 LEAST SQUARES BREED MEANS (±SE) FOR TIME TAKEN FOR RECTAL TEMPERATURE TO DROP FROM PMR TO 35° C (MINUTES). MODEL AS TABLE 19

BREED	N	TIME TAKEN FOR RECTAL TEMPERATURE TO DROP FROM PMR TO 35° C	BREED RANKING MAXIMUM = 1
Scottish Blackface	33	50.39 ± 7.84	1
Border Leicester	23	35.28 ± 8.68	7
Boreray Blackface	25	35.84 ± 15.28	5
Cheviot	35	47.03 ± 6.41	2
Finnish Landrace	23	30.93 ± 11.97	9
Tasmanian Merino	21	35.63 ± 8.61	6
Oxford Down	20	38.17 ± 11.59	4
Soay	38	31.50 ± 8.97	8
Southdown	26	11.76 ± 6.95	10
Welsh Mountain	21	41.67 ± 7.18	3

TABLE 21 LEAST SQUARES ANALYSIS, SIGNIFICANCE LEVELS, MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING FINAL RATE OF RECTAL TEMPERATURE FALL

VARIABLE	DF	MEAN SQUARE	F. RATIO	SIGNIFICANCE OF LEVEL
Day of Test	137	0.0033	0.97	NS
Breed	9	0.0101	2.96	P < 0.01
Weight	I	0.0183	5.35	P < 0.02
Age	1	0.0200	5.84	P < 0.02
Initial Rectal Temp.	1	0.0042	1.24	NS
Remainder	115	0.0034		

TABLE 22 LEAST SQUARES BREED MEANS (±SE) FOR FINAL RATE OF FALL OF RECTAL TEMPERATURE TO 35°C(°C/MIN.

BREED	FINAL FALL RATE	BREED RANK (FASTEST = 1)
Scottish Blackface	0.13 ± 0.03	8
Border Leicester	0.13 ± 0.03	7
Boreray Blackface	0.18 ± 0.06	4
Cheviot	0.11 ± 0.02	9
Finnish Landrace	0.19 ± 0.03	3
Tasmanian Merino	0.20 ± 0.03	2
Oxford Down	0.10 ± 0.04	10
Soay	0.18 ± 0.03	5
Southdown	0.23 ±0.02	1
Welsh Mountain	0.14 ±0.02	6

older animals showing slower fall rates.

Cold resistance was also fitted as an independent variable into models for metabolic rate parameters. In all cases, (peak metabolic rate, time peak held, location of peak and metabolic rate at 35 ^{o}C rectal temperature), cold resistance had a significant effect on the metabolic rate parameters tested ($p < 0.001$). A correlation 0.42 (264df $p < 0.001$) was found between cold resistance and peak metabolic rate for the raw data.

Correlations between cold resistance (LOGCCR) and other metabolic rate parameters are shown overleaf.

A general synopsis of results is given in Table 23.

Variable	Correlation with LOGCCR	Significance of Correlation (n=265)
Base Metabolic rate	0.09	N.S.
Metabolic rate at rectal temperature 35°C	0.3	P<0.001
Time peak metabolic rate held	0.36	P<0.001
Location of Peak metabolic rate from start to cool	0.68	p <0.001
Percentage drop in metabolic rate from peak to that at 35°C Rectal Temperature.	0.29	p<0.001
Time for Metabolic rate to drop from peak to that at rectal 35 °C.	0.78	p<0.001

TABLE 23 GENERAL SYNOPSIS OF RESULTS - SIGNIFICANCE LEVELS AFTER RELEVANT MODELS FITTED

DEPENDENT VARIABLES	FIXED EFFECTS				INDEPENDENT VARIABLES			
	BREED	SEX	LITTER SIZE	DAY OF TEST	WEIGHT	AGE	SKIN THICKNESS	INITIAL RECTAL TEMP.
COLD RESISTANCE	$P < 0.001$	NS	$P < 0.02$	$P < 0.001$	$P < 0.02$	NS	$P < 0.01$	$P < 0.01$
FINAL RATE OF FALL OF RECTAL TEMPERATURE	$P < 0.01$	NS	NS	NS	$P < 0.02$	$P < 0.02$	NS	NS
PEAK METABOLIC RATE PER UNIT BODY WEIGHT	NS	$P < 0.02$	NS	$P < 0.001$	NS	$P < 0.02$	NS	$P < 0.02$
PEAK METABOLIC RATE	NS	$P < 0.02$	NS	$P < 0.001$	$P < 0.001$	$P < 0.02$	NS	$P < 0.02$
BASE METABOLIC RATE PER UNIT BODY WEIGHT	$P < 0.02$	NS	NS	$P < 0.001$	NS	NS	NS	$P < 0.001$
BASE METABOLIC RATE	NS	NS	NS	$P < 0.001$	$P < 0.001$	NS	NS	$P < 0.001$
METABOLIC RATE AT 35°C RECTAL TEMPERATURE	NS	$P < 0.02$	NS	$P < 0.02$	NS	$P < 0.02$	NS	$P < 0.02$
LOCATION OF PEAK METABOLIC RATE FROM START TO COOL	NS	NS	NS	$P < 0.02$	NS	NS	$P < 0.02$	NS
PERCENTAGE DROP IN METABOLIC RATE BETWEEN PEAK AND RECTAL 35°C	NS	NS	NS	$P < 0.001$	NS	NS	NS	NS
TIME 5% OF PMR HELD	NS	NS	NS	NS	NS	NS	$P < 0.001$	NS
TIME FROM PMR TO RECTAL 35°C	$P < 0.01$	NS	NS	$P < 0.02$	NS	NS	NS	$P < 0.02$

DISCUSSION AND CONCLUSIONS

The significant effects of breed, weight and skin thickness on the ability of the newborn lamb to resist body cooling are discussed by Samson and Slee (1981), and some further analysis of these results is included here. The additional metabolic rate data presented here give some insight into the variation of some of the components of the other side of the heat balance equation, heat production.

Significant breed variation for metabolic rate once weight has been fitted is difficult to detect except in the case of base metabolic rate per unit weight where the three smallest breeds (Soay, Boreray Blackface and Finnish Landrace) have the highest BMR and the largest breeds (Oxford and Border Leicester) the lowest. In this latter (BMR) analysis, although non-significant, weight has an F ratio of greater than one in the model. The weight term is dropped as it is largely nonsensical to have weight on both sides of the regression with implied correlated errors in both terms. In the analysis of metabolic rate not expressed per unit weight, weight exerts a significant effect for both base and peak situations. There are of course significant breed differences for weight.

Sex also is significant with females having higher levels for both base and peak metabolic rate. This could have potential survival advantage, but the physiological mechanism governing this difference is difficult to identify. In this experiment data are corrected for weight, litter size, etc., the obvious variation not accounted for is hormonal. Sex differences for human thyroxine levels are found in adults with females having higher levels (Hall, Ormston, Besser, Cryer and McKendrick, 1972). Whereas immature

animals have higher levels than adults (Diem and Lentner, 1970), no evidence for sex differences has been reported.

For the age range studied, older animals have higher peak metabolic rates, ($p < 0.02$). This may be as a result of the younger animals heat production capabilities being impaired during periods of hypoxia experienced during parturition.

High initial rectal temperature (within normal levels) may allow greater peak metabolic rates to be expressed as a consequence of a longer period of cold stimulus before body temperature starts to limit metabolic response. High initial rectal temperatures are associated with high base metabolic rate as a result of the animal with a higher temperature having to maintain homeothermy at a greater thermal gradient with the environment.

Metabolic rate at a rectal temperature of 35°C is higher for the female; again this fact could lead to a species advantage in adverse conditions when a low male to female ratio could make maximum impact. The significant effect of high initial rectal temperature on metabolic rate at the rectal temperature of 35°C could reflect the fact that animals identified by higher initial rectal temperatures are better thermoregulators. Those with low initial rectal temperatures may be slightly hypothermic as a consequence of environmental cold stress. Age is also associated here; older animals have higher initial rectal temperatures.

Location of peak metabolic rate in the cooling schedule is significantly affected by skin thickness. This may be because the animals with greater skin thickness can offset the cold stimulus required to produce maximum metabolic effort as a consequence of their greater insulation. This argument may also hold for the

ability to maintain relatively high levels of metabolic rate for long periods. Skin thickness has a significant effect on the time 95 percent of PMR can be held, and this parameter may well be more significant in survival potential rather than the absolute peak value attainable.

Further analysis of cold resistance data shows significant breed effects for the time between PMR and rectal temperature reaching 35°C. As with cold resistance the hill breeds and Oxford perform best here. The three further variables (time from peak to metabolic rate at 35°C, cold resistance time and final rate of fall) encompassing various aspects of resistance to body cooling, all return significant breed variation. No significant breed rankings are found across the parameters although the Southdown and Finnish Landrace are always poor and hill breeds and Oxford do best.

Day of test has a significant effect on cold resistance time, peak, base and final metabolic rate at 35°C rectal temperature and time for rectal temperature to fall from PMR levels to 35°C. Initially the "year" of the test was fitted in the ANOVA model, data being collected over three years, in order to explain variation but results from these analyses was not very clear. No interaction trend with breed was found for cold resistance or peak metabolic rate. To further complicate the analysis not all breeds were tested in all years. Where comparison was possible between all three years mean trends were conflicting. Application of day of test in the analysis to incorporate year effects gives a better insight into the relationships, especially as specific environmental conditions are bound to have an effect on animal response. Incorporated into day of test variation is environment, technique (changes in recording and

measuring equipment) nutrition of lambs etc. An attempt was made to incorporate the effects of weather at the time of birth and test into the analyses using data from the Poultry Research Centre, Roslin weather records, but no significant relationships were identified.

WATERBATH VARIATIONS AND RECOVERY FROM TESTING

A number of variations on the general waterbath procedure were carried out throughout the period of the main experimentation in order to investigate the effect of different rates and types of cooling on performance; the effect of birthcoat types and the importance of birthcoat insulation on cold resistance.

(A) Rectal temperature to 32^{o}C.

Initially it was thought that whilst taking rectal temperature to 35^{o}C provided a suitable differentiating test between individuals without prolonging the procedure, perhaps below this temperature rectal temperature would start to fall more rapidly. This zone of complete thermoregulatory failure could be of interest of relevance to lamb survival. Eleven Soay lambs (this breed was in the middle of the ranking for cold resistance) were waterbathed according to usual procedure with rectal temperature taken to 32^{o}C before removal from the water. No significant difference was recorded between rectal temperature fall rate for the ten minutes prior to 35^{o}C (as already analysed) and subsequent fall rate 35 - 32^{o}C, (see Table 24).

(B) Fast Cooling Technique.

Once initial investigations (as in the main breed experiment) had

TABLE 24 RATES OF RECTAL TEMPERATURE FALL FOR THE TEN MINUTES PRIOR TO REACHING 35°C (AS PREVIOUSLY ANALYSED) AND FOR A FURTHER DROP FROM 35° - 32° IN ELEVEN SOAY LAMBS UNDER STANDARD WATERBATH TEST

LAMB IDENTITY	COLD RESISTANCE TIME TO 35°C(MINS)	(RANKING)	COLD RESISTANCE TIME TO 32°C(MINS)	(RANKING)	RATE OF RECTAL TEMP. FALL TO 35°C(10 MINS) °C/MIN.	RATE OF RECTAL TEMP. FALL FROM 35°C TO 32°C °C/MIN.
1	43	(4)	63	(4)	0.15	0.14
2	41	(6)	57	(6)	0.19	0.17
3	50	(1)	79	(1)	0.10	0.12
4	43	(4)	65	(3)	0.14	0.16
6	50	(1)	77	(2)	0.11	0.10
7	39	(8)	53	(9)	0.21	0.19
8	30	(10)	51	(10)	0.14	0.14
9	28	(11)	39	(11)	0.27	0.29
12	41	(6)	61	(5)	0.15	0.18
13	45	(3)	56	(7)	0.27	0.26
18	34	(9)	56	(7)	0.14	0.11

been carried out to identify areas of suitable variation with application to resistance to hypothermia, the next step would be to apply screening tests to a large population of lambs prior to selection of the various likely components of cold survival. This is likely to be best achieved in the location in which the sheep are kept, both for logistic and environmental reasons. Therefore there is a need to develop a secondary type of test for use on the farm. Here there is recourse to less sophisticated facilities and less specialised trained staff. The test will therefore have to be very easy to control and also allow a greater number of animals to be tested in one day as the lambing season is likely to be shorter in the commercial situation. For this reason investigation of a faster cooling procedure was tried. A comparative study of three different tests was carried out on Boreray lambs in 1979. The use of Borerays also allowed comparison of their response to different forms of cold stimulus as this had previously been demonstrated to vary appreciably according to the test applied (Slee, et al, 1980). Boreray and Scottish Blackface breed ranking for cold resistance was reversed for the two tests already tried. The initial test carried out during preliminary investigations started with a water temperature of 25°C and the standard waterbath procedure started at thermo-neutral temperatures.

Method. Eleven lambs were given each of three cold resistance tests, all with metabolic rate measurements taken. Three animals were dropped from analyses because of technical problems with the oxygen analyser after moisture had been drawn into one of the cells. All were given the standard waterbath on the first day and six were

given a 25°C waterbath on the next day with a new faster cooling procedure (described below) on the third day. The remaining five lambs were given the latter two tests in reverse order. The 25°C waterbath procedure was as described in Slee et al, (1980). The fast cool test was basically a faster version of the standard test in which water cooling rates were increased by recourse to colder water temperature (approximately 11°C),and a faster flow rate of 1.5 gallons/minute. Results for comparison of the three tests are given in Table 25,25A. Peak metabolic rates were calculated over a five minute period rather than ten minutes, as previously used, as some of the immersion times were quite short (minimum 15 minutes).

Results. Spearman's Rank Coefficients were fitted for cold resistance and peak metabolic rate estimates derived for each individual on each test. No significant rank correlations were found among tests on peak metabolic rate, but all tests were significantly correlated for cold resistance ($p < 0.01$).

(A Spearman's Rank correlation of 0.8 ($p < 0.001$) was obtained for cold resistance between the standard waterbath and 25°C waterbath cold stress test for data accrued in 1977-78 (in this case no metabolic rate measurements were taken on the 25°C waterbath lambs)).

(C) Recovery to rectal temperature 38°C

Method. After waterbathing the lambs were gently mopped with cotton wool and retained in a wire cage in a cabinet with two hot air fans positioned at a distance of about two feet. Rectal temperature was recorded at minute intervals until 38°C was reached, and the time to reach this level was recorded. The lambs were then dried off by

TABLE 25 COMPARISON OF COLD RESISTANCE RESULTS FOR THREE DIFFERENT WATERBATH COLD STRESS TESTS ON BORERAY LAMBS

ANIMAL IDENTITY	COLD RESISTANCE TIME (MINS.) 37°C WATERBATH	25°C WATERBATH	FAST COOL
1	57	15	30
2	43	27	31
3	49	21	39
4	54	24	43
5	75	89	48
6	58	28	48
7	77	69	60
8	75	62	45
9	57	30	37
10	52	24	39
11	68	62	59
Mean ± SE	60.5 ± 3.48	41.0 ± 7.45	43.5 ± 2.98

TABLE 25A COMPARISON OF PEAK METABOLIC RATES FOR THREE DIFFERENT WATERBATH COLD STRESS TESTS ON BORERAY LAMBS

ANIMAL IDENTITY	PEAK METABOLIC RATE (ML O_2/Kg min) 37°C WATERBATH	25°C WATERBATH	FAST COOL
1	76.3	70.2	64.6
2	61.2	66.1	58.4
3	63.7	59.4	59.4
4	58.8	60.5	76.8
5	*	67.8	*
6	*	60.5	54.0
7	*	76.4	81.5
8	70.0	69.2	69.8
9	61.3	69.8	65.2
10	73.2	66.6	56.2
11	68.5	63.8	65.1
Mean ±SE	65.8 ± 2.14	66.4 ± 1.54	65.1 ± 2.81

* Estimation lost - equipment malfunction

hand and returned to their dams.

Results. Once removed from the waterbath an afterdrop in rectal temperature of between 0.5 and 1°C was recorded in rectal temperature. Precise quantification of this drop was not made as rectal probes were changed between waterbath and recovery room. Results for recovery time are shown in Table 26. Mean recovery across all breeds was 24 ± 0.39 minutes. No significant breed differences were found after least squares analysis although it was noted that the Soay lambs coat dried out more quickly than the other breeds. Great variation was noted in the activity of individual lambs at depressed rectal temperature. The feral breeds were active at lower rectal temperatures whereas some lowland breeds, notably the Border Leicester, were very lethargic during the rewarming process. There was no significant correlation between rate of recovery and cold resistance time.

A number of Scottish Blackface lambs were allowed to recover temperature passively inside an insulated box. The box was made with one and half inch Styrofoam (extruded polystyrene foam) with air/water draining holes located in the sides. The box was placed in a climate chamber at 1°C.

Results of this technique are shown in Table 27. All individuals showed a reverse in rectal temperature fall, with the majority producing rates of rectal temperature rise equivalent to the actively dried lambs. In this case the lambs were still wet after temperature recovery but the technique illustrates the beneficial effects of shelter provision to the hypothermic lamb.

TABLE 26 LEAST SQUARES ANALYSIS SIGNIFICANCE LEVELS MEAN SQUARES AND F RATIOS FOR ALL VARIABLES AFFECTING RECOVERY TIME FROM 35° TO 38°C RECTAL TEMPERATURE

VARIABLE	DF	MEAN SQUARE	F RATIO	SIGNIFICANCE LEVEL
Breed	9	33.19	1.14	NS
Day of Test	137	39.80	1.37	P < 0.02
Litter size	2	99.28	3.42	P < 0.02
Weight	1	60.77	2.09	NS
Initial Rectal Temp.	1	196.79	6.78	P < 0.02
Remainder	113	29.04		

TABLE 27 PASSIVE RE-WARMING OF TWELVE SCOTTISH BLACKFACE LAMBS

LAMB IDENTITY	1ST RECTAL TEMP. RECORDED IN RE-COVERY BOX	RECTAL TEMPERATURE RECORDED AT 20 MINS	RISE RECORDED IN 20 MINS. °C
61	33.9	37.4	3.5
66	32.9	35.6	2.7
75	33.3	37.6	4.3
79	33.8	37.0	3.2
86	32.9	37.7	4.8
82	32.6	37.6	5.0
88	34.1	37.0	2.9
91	33.6	37.4	3.8
87	33.3	38.1	4.8
95	33.1	36.0	2.9
102	32.1	37.4	5.3
105	34.3	36.1	1.8

BIRTHCOAT EFFECTS.

That birthcoat variation may not be expressed under waterbath conditions has already been discussed. A series of experiments were designed to compare the performance of birthcoat extreme types under both waterbath and wind tunnel conditions. The Welsh Mountain lines for extreme hairy and fine birthcoat as developed by genetic selection at ABRO'S Rhydyglafes Farm provide ideal ~~data~~ Subjects for this investigation, the phenotypic difference between fine and hairy coat types being distinct. Methods and results will be detailed under experimental headings with a general discussion section to follow.

EXPERIMENT 1. Waterbath cold stress comparison for Welsh Mountain hairy and fine coated lambs.

METHOD. Twenty fine coated, and twenty six hairy coated lambs were selected from the offspring of forty Welsh Mountain ewes for use in this experiment (a further seventeen from the same dam pool were clipped and used in Experiment 2). One lamb with an intermediate class birthcoat was discarded from the experiment.

All lambs were given the standard waterbath cold stress. In addition lambs were wool sampled (post-test) over a 40mm square taken from the midside. Samples were dried, weighed and the results expressed as g/2000mm2.

RESULTS. Physical characteristics of the tested lambs together

with cold resistance and metabolic rate estimates are given in Tables 28 and 28A. Metabolic rate data are missing in a few cases as a result of technical difficulties with data logging equipment. Significance levels for t tests on these various parameters are recorded in Table 29. There was no significant difference in weight or age between the fine and hairy coated lambs. Mean fleece depth for hairy lambs was more than twice that for fine coated lambs, and wool weight was significantly greater for the former. Significant skin thickness differences between coat types may be to some extent inter-related with coat characteristics. The skin thickness measurement as well as including a factor representing different external densities of coat will also probably reflect greater dermal follicle development for the hairy lambs. Skin thickness is significantly correlated with fleece depth ($p < 0.01$).

No significant variation between coat types was found for PMR. BMR was greater for fine coated lambs. Greater metabolic effort must be required to maintain homeothermy when insulation (tissue and fleece) is less than that of the hairy lambs.

Cold resistance was significantly greater in the hairy coated lambs ($p < 0.01$).

EXPERIMENT 2. Waterbath cold stress comparison for "clipped" Welsh Mountain lambs of hairy and fine birthcoat types.

Objective: This experiment was as an extension of Experiment 1, to see if differences in cold resistance for fine and hairy coated lambs disappeared when the effect of coat was removed.

METHOD. Nine fine and eight hairy coated lambs from the same

TABLE 28 WATERBATH RESULTS AND PHYSICAL DATA FOR 20 WELSH MOUNTAIN FINE COATED LAMBS

LAMB IDENTITY	WEIGHT (KG)	SKIN THICKNESS (mm)	AGE (HRS)	FLEECE DEPTH (cm)	WOOL WEIGHT ($g/2000mm^2$)	PEAK METABOLIC RATE (ml O_2/Kgmin)	BASE METABOLIC RATE (ml O_2/Kgmin)	WATERBATH COLD RESISTANCE (mins)
3	2.9	3.0	23	0.5	0.478	-	-	49
4	2.5	3.1	30	0.6	0.415	77.94	23.2	49
*9	2.0	2.3	26.5	0.5	0.258	55.01	22.0	29
*10	3.0	3.1	27	0.7	0.339	-	-	29
17	4.2	4.3	10	0.9	0.565	54.71	15.7	57
20	3.3	3.5	38.5	0.7	0.341	-	-	42
21	3.5	3.3	39	0.9	0.295	48.11	19.6	42
28	3.5	3.5	22.5	0.8	0.481	61.31	-	34
29	3.2	3.4	24.5	0.8	0.473	58.50	15.0	45
30	2.9	3.7	21	1.1	0.451	66.21	-	56
31	3.3	3.6	22.5	0.7	0.441	68.59	12.4	78
*32	3.0	4.0	20	0.7	0.445	58.51	12.8	34
*36	3.1	3.3	7.5	0.7	0.293	51.81	-	49
*37	3.0	3.7	9	0.6	0.398	61.01	-	47
*44	3.85	3.4	27.5	0.6	0.368	59.81	14.4	60
*45	3.15	3.3	28.5	0.8	0.475	61.91	12.5	49
54	2.1	3.7	45	0.4	0.476	66.91	21.2	60
*55	4.1	4.1	47	0.9	0.486	64.81	20.2	46
72	4.1	3.5	51.5	0.6	0.352	58.21	21.7	55
73	2.9	3.3	53	0.5	0.300	61.31	16.6	43
Mean ±SE	3.18 ± 0.13	3.46 ± 0.06	29 ± 2.98	0.7 ± 0.04	0.40 ± 0.021	n =17 60.89 ± 1.64	n = 13 17.48 ± 1.10	47.65 ± 2.62

* repeated in wind tunnel

TABLE 28A WATERBATH RESULTS AND PHYSICAL DATA FOR 26 WELSH MOUNTAIN HAIRY COATED LAMBS

*repeated in wind tunnel

LAMB IDENTITY	WEIGHT (KG)	SKIN THICKNESS (mm)	AGE (HRS)	FLEECE DEPTH (cm)	WOOL WEIGHT (g/2000 mm^2)	PEAK METABOLIC RATE (ml O_2/Kg min)	BASE METABOLIC RATE (ml O_2/Kg min)	WATERBATH COLD RESISTANCE (mins)
1	3.8	3.9	18	2.2	0.685	56.80	16.7	47
2	3.1	4.1	19	2.1	0.968	64.69	11.5	50
5	2.7	3.8	42	2.3	0.959	57.21	-	54
6	3.25	3.9	43	2.1	1.047	66.51	-	55
8	2.8	3.7	23	1.8	0.539	66.75	18.0	46
7	2.8	3.7	24	1.8	0.626	-	-	44
*12	3.1	3.5	18	1.6	0.553	55.71	-	42
*13	3.25	3.8	19	2.0	0.568	48.51	-	56
*15	2.5	4.0	25.5	2.1	0.572	43.21	-	50
*16	2.6	3.4	26.5	2.0	0.598	55.90	14.2	71
18	2.5	3.9	22.5	1.8	0.575	-	-	73
19	3.0	4.6	24.5	2.2	0.705	53.21	9.1	91
22	2.9	4.4	28	1.9	0.685	61.86	15.7	69
23	2.75	3.7	33	2.0	0.710	54.49	14.4	60
24	3.1	3.9	25.5	1.8	0.517	65.41	18.0	67
25	2.95	3.9	27	1.7	0.624	57.01	13.4	38
26	3.15	4.2	26	2.1	0.618	-	-	61
27	3.2	3.8	27	1.9	0.783	-	-	63
33	4.0	4.5	15.5	2.1	0.734	67.41	13.6	129
34	3.0	3.8	27	2.2	0.633	47.95	15.0	57
35	3.3	3.8	28.5	1.9	0.771	60.61	14.5	81
38	3.8	4.7	26.5	2.3	1.215	66.31	-	76
39	3.0	4.3	28	2.2	0.814	63.31	15.8	64
*46	4.35	4.8	20	2.0	0.821	50.79	11.5	113
*49	2.55	3.3	48.5	1.5	0.671	54.53	13.9	77
*50	2.8	3.5	50	1.5	0.516	63.32	16.4	62
Mean	3.09	3.96	27.52	1.97	0.71	n = 22	n = 15	65.23
± SE	± 0.09	± 0.08	± 1.77	± 0.04	± 0.033	58.25 ± 1.48	14.4 ± 0.64	± 4.11

TABLE 29 SIGNIFICANCE LEVELS FOR t TESTS AND REGRESSIONS ON DEPENDENT AND INDEPENDENT VARIABLES PERTAINING TO WATERBATH TESTS COMPARING FINE AND HAIRY COATED WELSH MOUNTAIN LAMBS

VARIABLE	n	TEST	SIGNIFICANCE LEVEL FINE - HAIRY COAT
Weight	46	t = 0.06	NS
Age	46	t = 0.35	NS
Skin Thickness	46	t = 4.12	P < 0.001
Fleece Depth	46	t = 20.7	P < 0.001
Wool Weight	45	t = 7.08	P < 0.001
Waterbath Cold Resistance	46	t = 3.36	P < 0.01
Peak Metabolic Rate	39	t = 1.18	NS
Base Metabolic Rate	30	t = 2.51	P < 0.02
Linear Regressions			
Skin Thickness/Fleece Depth	46	r = 0.41	P < 0.01
Fleece Depth/Wool Weight	46	r = 0.65	P < 0.001

parental stock as in Experiment 1 were clipped immediately prior to waterbathing. Numbers were minimised in this experiment because of the housing requirement after experimentation and the presumed mothering-up problems. Skin thickness measurements were not taken after clipping because attempts at measurement of the bare skin resulted in minor tearing injury which was not thought to be acceptable because of risk of infection from the waterbath. The standard waterbath cold stress was applied. Particular care was taken when rewarming and drying the clipped animals so as not to burn the skin.

RESULTS. There was no significant difference in weight or age between the two groups (Table 30). Pre-clipping fleece depth was significantly greater in the hairy lambs ($p < 0.01$). PMR, again was not affected by coat type, but BMR was, as in Experiment 1, being higher in the ex-fine coated lambs ($p < 0.02$). Cold resistance was also still greater for the ex-hairy coated lambs ($p < 0.01$).

In practice, none of the presumed mothering-up problems were experienced. Ewes and lambs were housed until wool regrowth was sufficient for turn out (about four weeks).

EXPERIMENT 3. Comparison of waterbath and wind tunnel cold stress tests for eight fine and eight hairy coated Welsh Mountain lambs (previously waterbathed in Experiment 1).

Objective: To study whether a test employing wind and rain would allow the effects of coat insulation on cold resistance to be more clearly demonstrated.

TABLE 30 WATERBATH RESULTS AND PHYSICAL DATA FOR 9 FINE and 8 HAIRY COATED WELSH MOUNTAIN LAMBS CLIPPED PRIOR TO TESTING

	LAMB IDENTITY	WEIGHT (KG)	AGE (HRS)	FLEECE DEPTH PRIOR TO CLIP	WATERBATH COLD RESISTANCE (MINS)	PEAK METABOLIC RATE (ML O_2/KG.MIN)	BASE METABOLIC RATE (ML O_2/KG.MIN)
HAIRY	41	2.8	8	2.5	39	53.02	18.1
	40	2.75	9	2.1	51	52.42	16.2
	42	3.5	27.5	2.1	49	65.12	16.8
	43	3.3	29	1.8	51	59.62	17.3
	47	3.0	28.5	1.8	63	65.42	16.3
	48	2.6	30	2.1	51	62.32	16.3
	60	3.5	43	1.9	48	71.32	16.9
	61	3.0	44	2.1	28	58.92	16.1
Mean ± SE		3.06 ± 0.12	27.38 ± 4.71	2.05 ± 0.08	47.5 ± 3.62	61.02 ± 2.27	16.75 ± 0.24
FINE	58	3.9	40	0.8	35	52.31	18.6
	62	3.0	19.5	0.6	32	48.95	18.7
	63	3.55	21	0.8	42	69.02	24.4
	66	3.5	23	0.8	40	60.72	20.2
	67	3.45	24	0.7	38	61.61	17.8
	68	3.7	15.5	1.0	35	56.22	16.5
	69	3.6	16.5	0.8	38	58.34	16.4
	77	2.5	32	0.7	32	54.32	19.6
	78	2.9	34	0.7	32	59.68	22.6
Mean ± SE		3.34 ± 0.15	25.06 ± 2.81	0.77 ± 0.04	36 ±1.24	57.91 ± 1.96	19.42 ± 0.89

METHOD. A number of preliminary wind tunnel tests employing various combinations of wind, rain and temperature were investigated. before a standard procedure was adopted. The test had to be severe enough to produce depressed rectal temperature even for the hairy coated lambs in a reasonable time, but recourse to temperatures below freezing point for any length of time would be likely to produce cold injury as a result of "rain" water freezing on the mesh of the retaining crate. The wind tunnel apparatus as described in the Equipment Section and illustrated in Fig 9 was housed in the climate chamber for this experiment in order to produce a controllable cooling regime.

The test applied was as follows:-

CONDITIONS	DURATION
Settle in crate with air supply/exhaust mask fitted. Room temperature - 1°C.	10 minutes
Introduce a 15mph wind directed to the right hand side of the lamb.	10 minutes
Introduce artificial rain water (8°C) at a rate of 0.5 gallons/minute together with wind.	25 minutes
Switch off rain, set temperature to fall towards -10°C.	20 minutes
Total cold stressed time	55 minutes

The time for rectal temperature to drop to 35°C was recorded from the point of introduction of the wind. In the case of more resistant hairy coated lambs this time was extrapolated.

Metabolic rate and rectal temperature were recorded at minute intervals. Lambs were prevented from lying down during the experiment by a wooden bar under the abdomen.

After the experiment, lambs were dried off and returned to their mothers.

RESULTS. Again no difference in weight or age of lambs between the two groups of lambs was imposed on the test. Results are recorded in Table 31. No significant variation in PMR was recorded. BMR estimations were not made under wind tunnel conditions because there was no controlled period at thermoneutrality. Wind tunnel cold resistance differences between hairy and fine coated lambs are highly significant ($p < 0.001$). All but one of the hairy coated individuals had to have an extrapolated cold resistance time, whereas no extrapolation was required in fine coated lambs. For the same sixteen lambs under waterbath cold stress (Experiment 1) cold resistance was also significantly different ($p < 0.02$). A Spearman's Rank correlation coefficient was calculated for individual cold resistances as derived from waterbath and wind tunnel tests across both coat types, RHO = 0.78 ($p < 0.01$). No significant correlation existed for PMR data.

DISCUSSION.

Differences in cold resistance time between hairy and fine coated lambs of the same breed are widened in the wind tunnel over

TABLE 31 WIND TUNNEL RESULTS FOR 8 FINE AND 8 HAIRY COATED WELSH MOUNTAIN LAMBS PREVIOUSLY WATERBATHED

	LAMB IDENTITY	AGE (HRS)	WEIGHT (KG)	MAXIMUM METABOLIC RESPONSE ($ML.O_2/KG.MIN.$)	WIND TUNNEL COLD RESISTANCE (MINS) * (RANK)	WATERBATH COLD RESISTANCE (RANK)
HAIRY	50	71	2.9	65.17	69 (7)	62 (5)
	49	70	2.6	58.85	85 (5)	77 (3)
	46	41	4.1	46.68	90 (2)	113 (2)
	33	65.5	4.6	58.70	95 (1)	129 (1)
	16	56	2.95	56.95	83 (6)	71 (4)
	15	54.5	2.7	50.65	87 (4)	50 (7)
	12	42	3.25	55.34	41 (8)	42 (8)
	13	43	3.3	58.23	90 (2)	56 (6)
Mean ± SE		55 ±4.43	3.30 ±0.25	56.32 ±1.98	80 ±6.20	75 ±10.88
FINE	55	89	4.5	51.33	55 (1)	46 (5)
	45	52	3.2	46.88	29 (6)	49 (2)
	44	51	3.7	55.94	35 (5)	60 (1)
	37	34	3.2	63.47	45 (3)	47 (4)
	36	33	3.2	55.55	46 (2)	49 (2)
	32	72.5	3.25	48.46	28 (7)	34 (6)
	9	50.5	2.1	52.05	25 (8)	29 (7)
	10	51	3.1	56.90	39 (4)	29 (7)
Mean ± SE		54 ±6.60	3.28 ±0.24	53.82 ±1.87	38 ±3.69	43 ±3.92

* extrapolated if > 55 mins.

the waterbath test. In the wind tunnel there was a 73 percent difference between hairy and fine coated lambs and in the waterbath this difference was 43 percent. After hairy and fine coated lambs of similar type were clipped their cold resistance still differed, but by a smaller amount (24.2 percent). Therefore there is a physiological difference between hairy and fine coated lambs apart from coat insulation.

With no significant group weight or age differences or biased sex distributions imposed on the comparisons, and no breed effects to be considered; the major source of variation was probably skin thickness. Skin thickness insulation is closely related to fleece type, the relative contribution of the fleece will depend on coat type.

PMR shows no variation with coat type. Metabolic rate measurements were thought to be unreliable during the wind/rain tests as it appeared that the lamb was subjected to much more stress than in the waterbath situation. Sudden shocks are experienced when the wind and rain are turned on and the natural instinct to lie down was prevented so as not to influence metabolic rate. In the waterbath test the changes in stress are more gradual and the animal had a long period of adjustment to its unfamiliar environment before cold exposure began.

Significant differences in BMR were probably a direct consequence of the poorer insulation of the fine coated lambs.

EXPERIMENT 4. Skin temperatures of hairy and fine coated Welsh Mountain lambs during cold exposure in a wind tunnel.

Objective: To obtain information on the insulative properties of

two different birthcoat types.

METHOD. Seven hairy and ten fine coated lambs were cold exposed in the wind tunnel with skin temperatures measured as well as metabolic rate and rectal temperature. The test applied was not as severe as in Experiment 3 as no significant depression in rectal temperature was desired in order to allow comparison between coat types irrespective of rectal temperature influences. The test used was as below:-

CONDITIONS	DURATION
Settle in still air (5°C)	10 minutes
Wind (15mph)	10 minutes
Wind and Rain	2 minutes
Wind to dry	8 minutes
No wind	5 minutes
	Total time = 35 minutes

Eleven skin temperatures were recorded from various sites (see Table 33) with thermocouples attached with glue to point shaved areas and isolated with waterproof tape.

RESULTS. Physical data for the lambs tested is shown in Table 32. No significant variation for weight, age and skin thickness was recorded between coat types. Wool weight variation was significant ($p < 0.001$). Graphs G1 and G2 illustrate, for one hairy and one fine

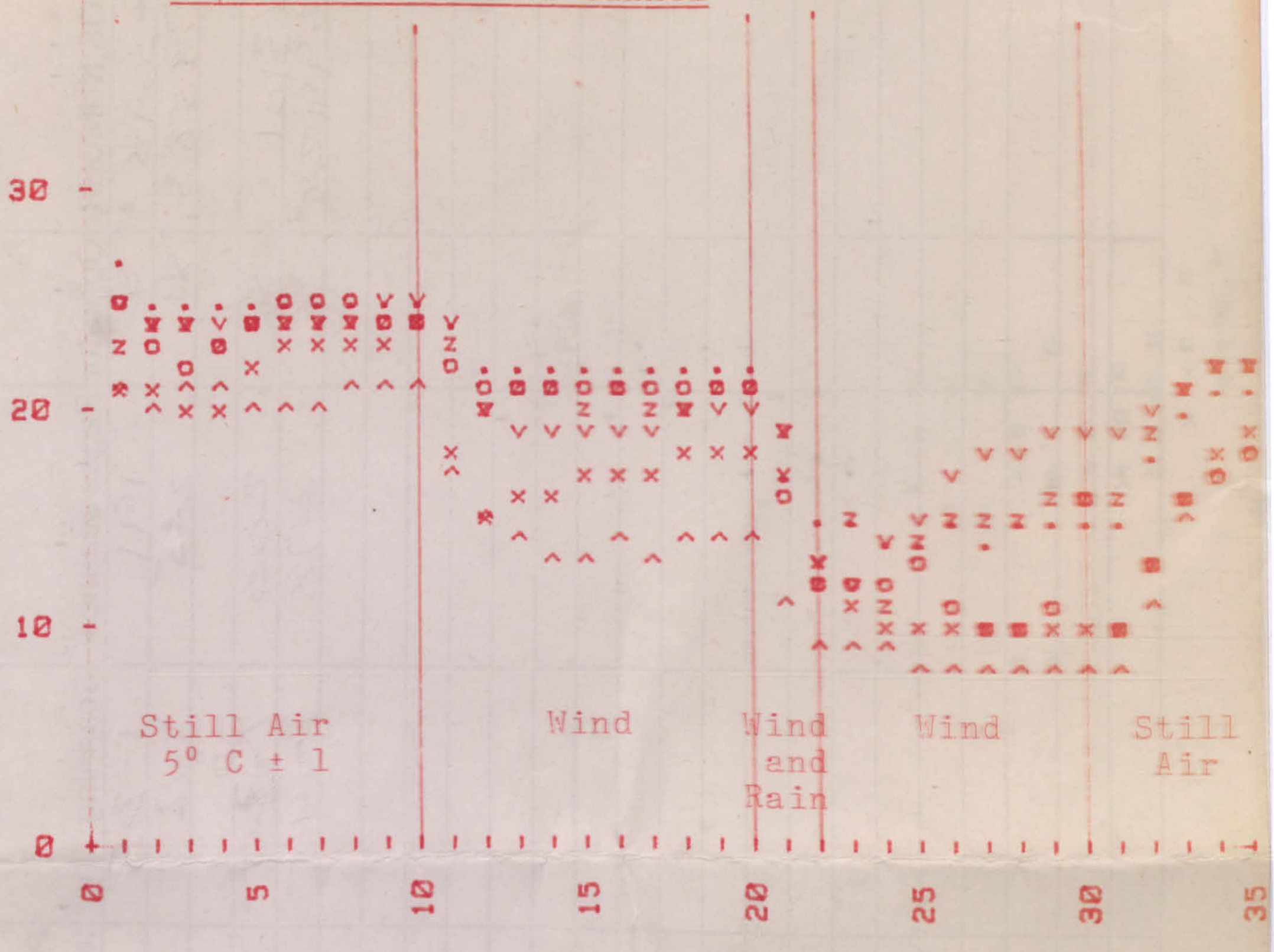
TABLE 32 WELSH MOUNTAIN LAMBS USED IN SKIN TEMPERATURE RECORDINGS DURING COOLING IN A WIND TUNNEL

	LAMB IDENTITY	SKIN THICKNESS	AGE (HRS)	WOOL WEIGHT g/2000mm²	WEIGHT KG.
HAIRY	16	3.15	7.25	.659	3.15
	4	3.36	24	.658	2.65
	17	3.48	8.5	.628	3.1
	3	3.92	23	.635	2.65
	9	4.24	28	.722	3.1
	13	4.40	22.5	.548	4.1
	18	4.42	17	.681	3.45
	Mean ± SE	3.85 ±0.20	18.61 ±3.03	.65 ±0.019	3.17 ±0.189
FINE	8	3.10	28	.508	3.1
	12	3.12	150	-	4.4
	2	3.48	64	.397	3.0
	6	3.76	38	.594	3.5
	11	3.90	80	.371	4.8
	7	3.96	27	.413	3.35
	10	4.16	25.5	.528	3.9
	5	4.50	11	.363	3.7
	14	3.34	25	.381	3.05
	15	3.78	26.5	.592	3.2
	Mean ± SE	3.72 ±0.14	47.5 ±13.11	.46 ±0.03	3.60 ±0.193

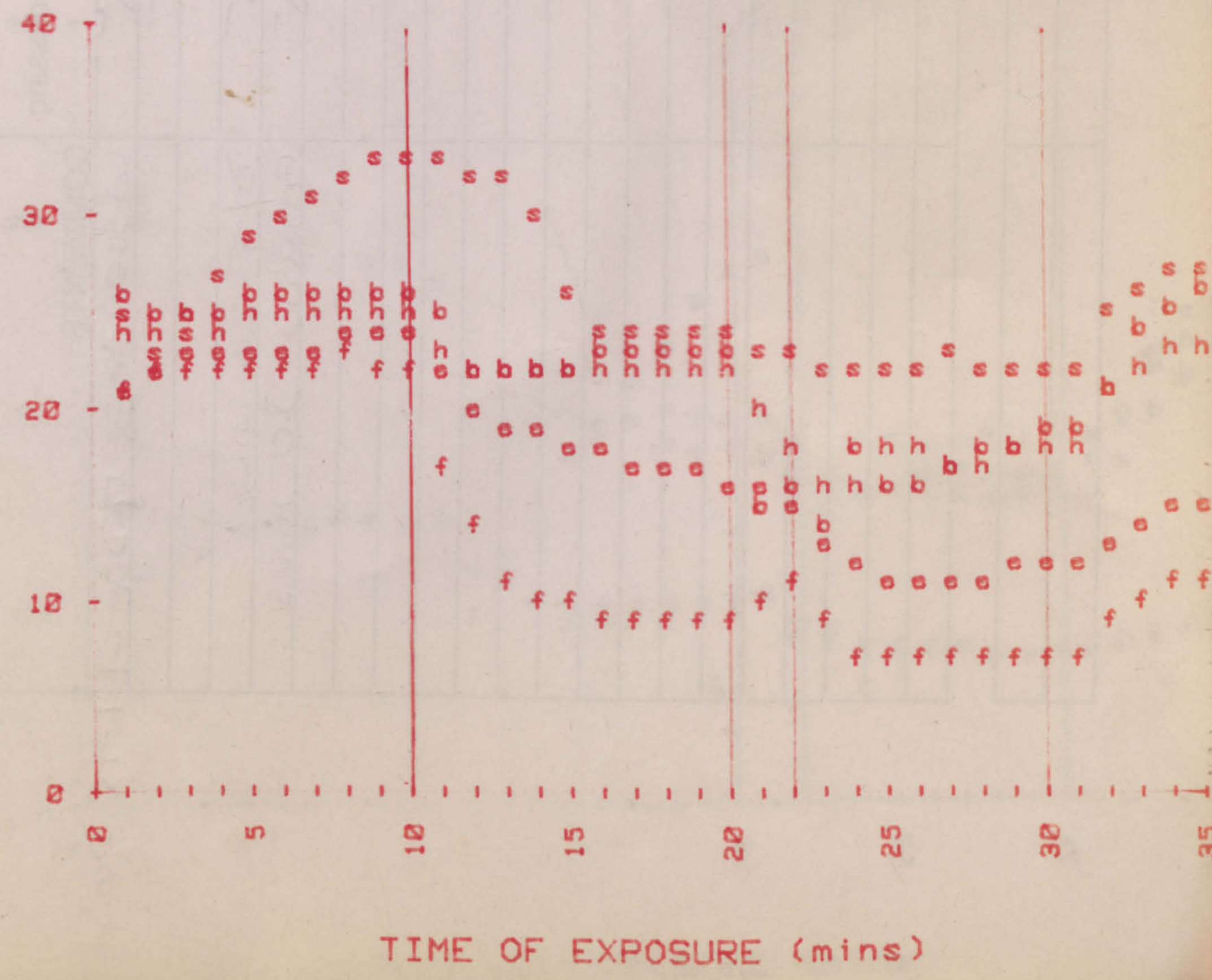
TABLE 33 KEY FOR IDENTIFICATION OF SKIN THERMOCOUPLE POSITION FROM GRAPHS G1 AND G2

SYMBOL	SITE
e	ear
f	foot
s	stomach
h	head
b	midback
•	left midside
o	right midside
z	left britch
x	right britch
v	left forequarter
^	right forequarter

GRAPH G1 Skin temperatures for a hairy coated Welsh Mountain lamb during cold exposure in a wind tunnel

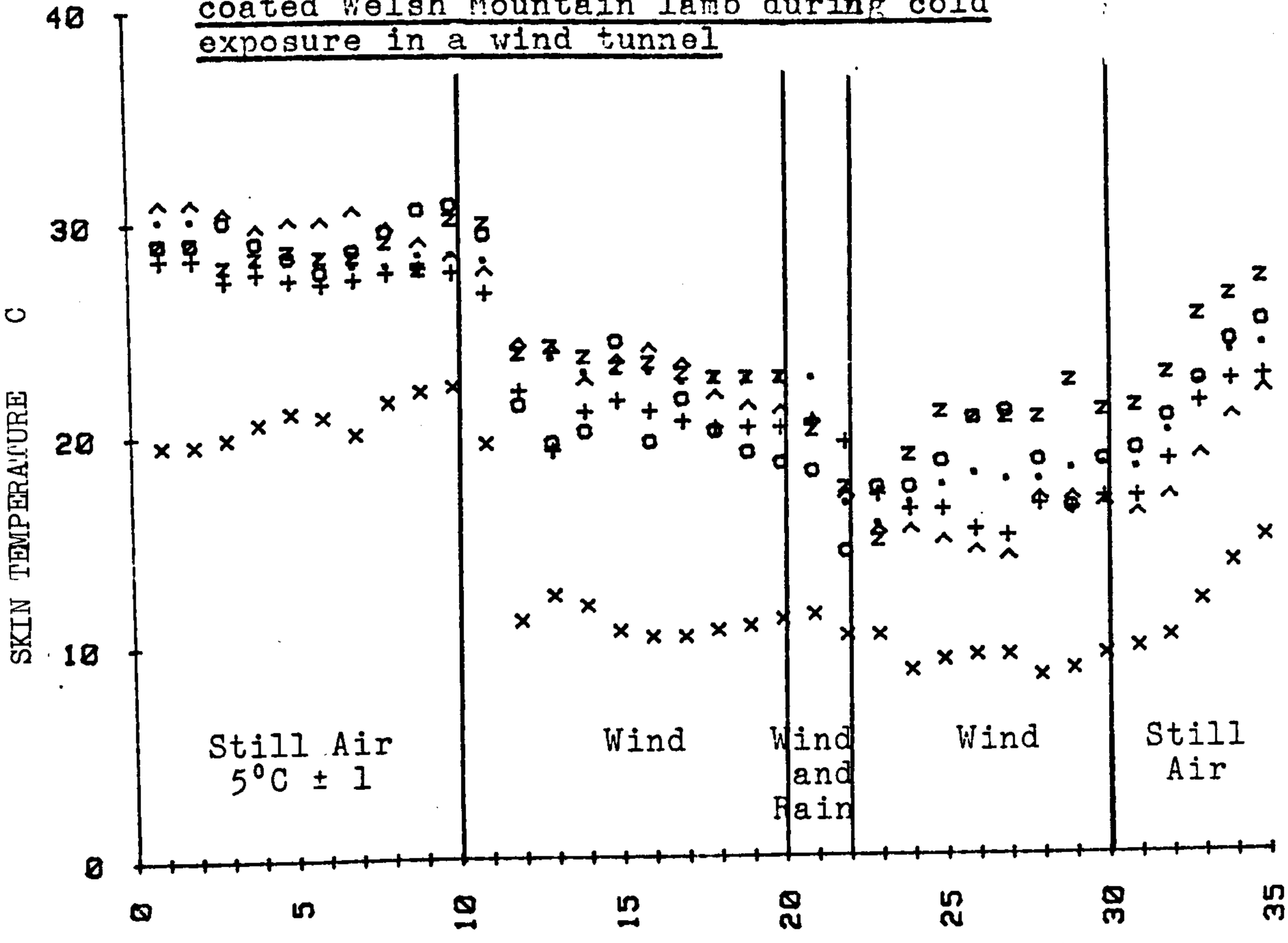


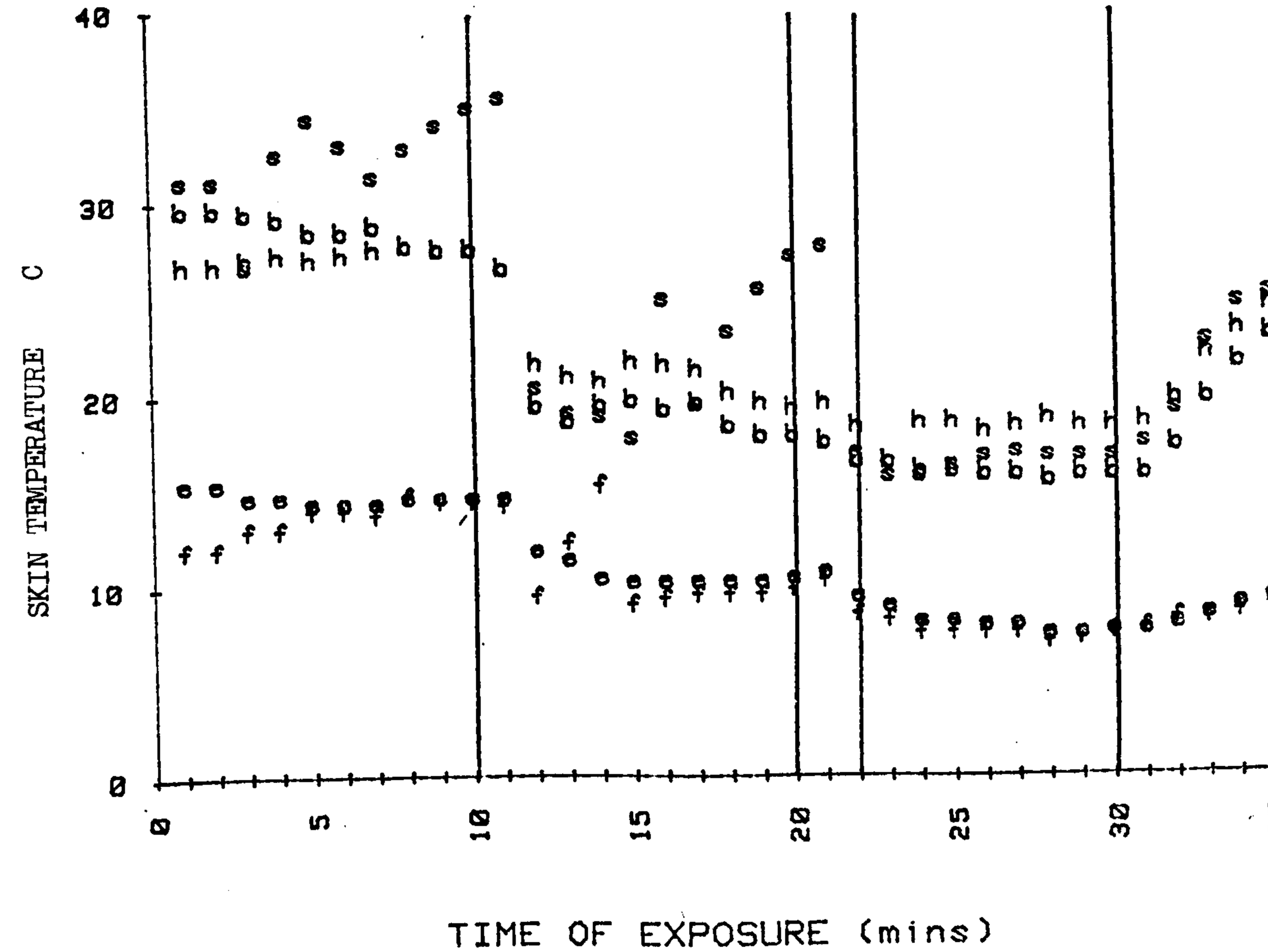
TIME OF EXPOSURE (mins)



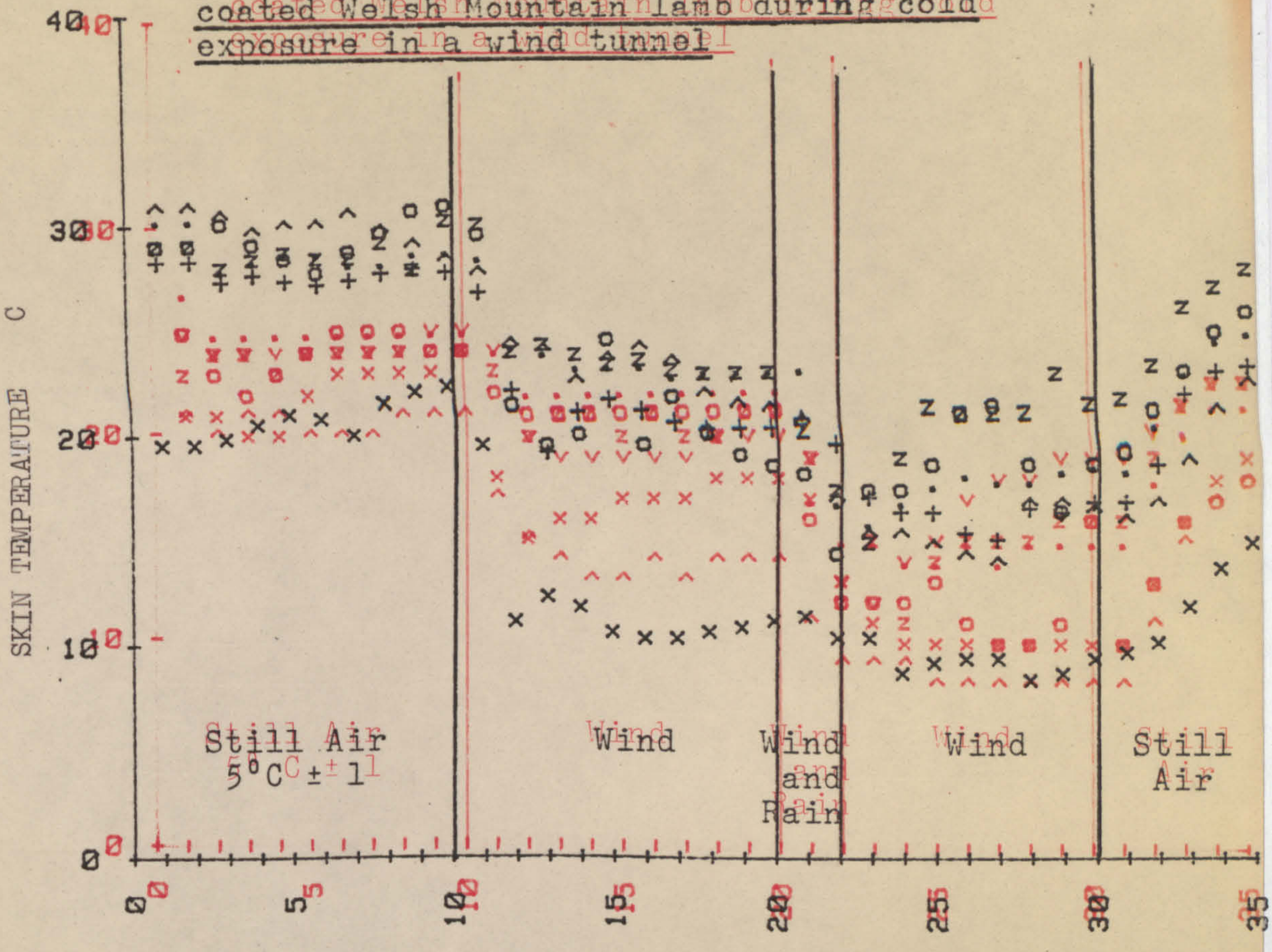
TIME OF EXPOSURE (mins)

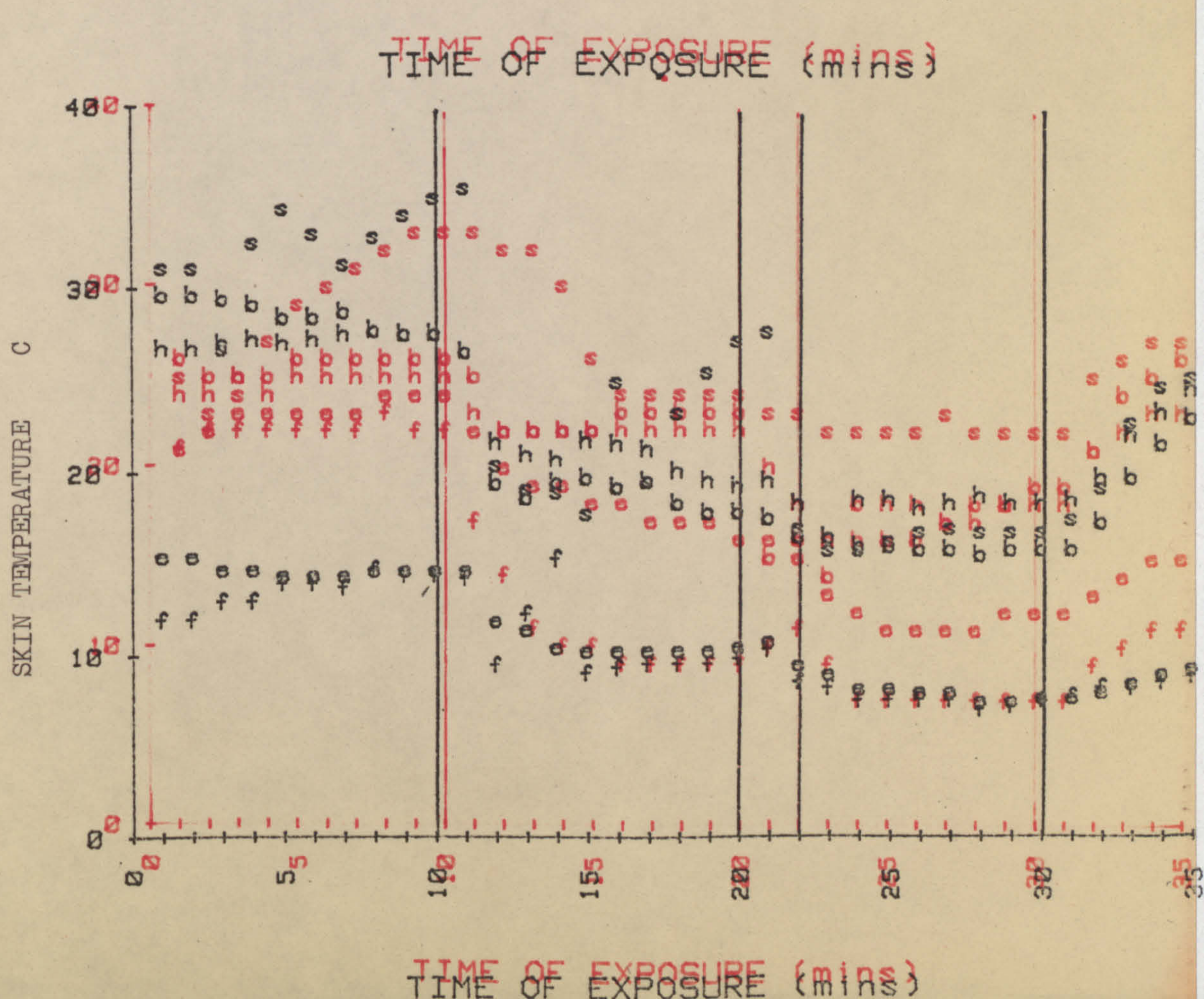
GRAPH G2 Skin temperatures for a fine coated Welsh Mountain lamb during cold exposure in a wind tunnel





GRAPH G2 Skin temperatures for a fine coated Welsh Mountain lamb during cold exposure in a wind tunnel





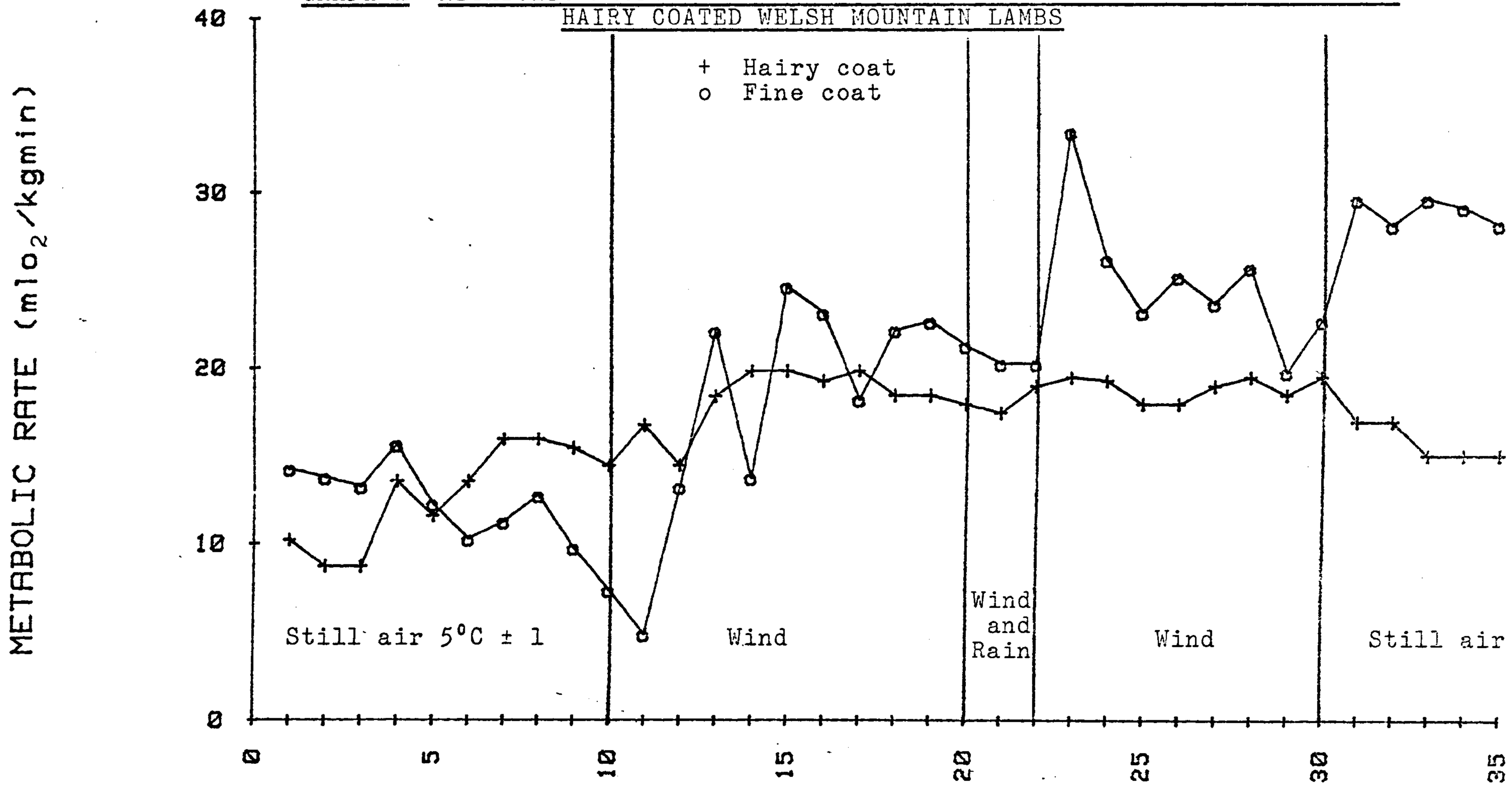
coated lamb under investigation, comparatively, the typical skin temperature response of each coat type to the test. Two graphs are used for each coat type to avoid confusion of the data.

In all cases, rectal temperature did not drop more than 0.5°C below the initial rectal temperature during the exposure. Metabolic rate response in the lamb coat types (for the same lambs as skin temperature illustrated) are shown in Graph H.

The first "still air" period was used to calculate base levels while the animal settled in the equipment. Metabolic rates for both animals were low, 12.8 and 12.1 ml02/Kgmin for hairy and fine coated lambs respectively. Skin temperatures during this settling in period were generally higher for the fine coated lambs. Skin temperature difference between coat types is most noticeable in extremity differences, when the ears and feet of the fine coated lamb are vasoconstricted from the start. After ten minutes a 15mph wind was directed to the right hand side of the animal, skin temperatures dropped in both cases in immediate response. The foot of the hairy lamb now vasoconstricted and the ear followed more slowly. Again the fine coated lamb's temperatures were the highest except for vasoconstricted feet and ears. For both coat types it was the right hand (windward) side of the animal where temperatures were depressed most. Another temperature drop occurred when the rain water was experienced. Once the coat had dried out and "still air" prevailed the skin temperature started to increase.

The metabolic heat production of the fine coated lamb exceeded that of the hairy coated throughout the cold exposure (except at base) (Graph H).

GRAPH H METABOLIC RESPONSE TO COLD STRESS IN A WIND TUNNEL FOR FINE AND HAIRY COATED WELSH MOUNTAIN LAMBS



NON-SHIVERING THERMOGENESIS

The importance of NST in the survival of neonatal mammals has been discussed in the Literature Review. The experimentation to follow was initially to provide a suitable technique for NST stimulation in the lamb by administration of noradrenaline and measurement of resultant heat production. This technique was then to be utilised in further experiments. Preliminary tests were tried with i.v. administration on Scottish Blackface lambs (Experiment 1) and subcutaneous injection in a small breed comparison trial (Experiment 2). Finally a more comprehensive experiment was carried out using Cheviot lambs to investigate the level of NST relative to the maximum metabolic response to cold stimulation.

EXPERIMENT 1

Thermogenic responses to intravenous noradrenaline in Scottish Blackface lambs (1978).

AIMS:-

(a) To demonstrate the thermogenic responses of the neonatal lamb to I.V. noradrenaline and to establish a technique for further experimentation.

(b) To assess the feasibility of jugular cannulation as a technique for administering noradrenaline where a number of comparative tests are to be carried out in one day.

(c) To illustrate the effect of age on the thermogenic response in one breed.

METHOD. Nine Scottish Blackface lambs, all twins, varying in age from four and a half to seventy one hours were cannulated via the jugular vein (with the kind assistance of M. Fordyce) and placed in a waterbath with access to an indirect calorimeter (equipment described in the main experiment). Base metabolic rate was established with the water temperature adjusted to thermoneutrality (around 37°C) and with a saline solution being infused. Once BMR was established, noradrenaline at the rate of 5µg per kilogram body weight per minute was administered i.v., this dose being sufficient to be active for thirty minutes (Jansky, 1973, Alexander and Williams, 1967). As the thermogenic response was initiated the water temperature was lowered by 2°C to allow more effective heat dissipation from the animal and so prevent hyperthermia. After thirty minutes a saline solution was infused for a further period until the thermogenic responses to the catecholamine were reduced. Rectal temperature and oxygen consumption were recorded at minute intervals throughout the procedure and respiration rates were counted at base, ten minutes and thirty minutes. All animals were held at as near equivalent temperatures as possible prior to the experiment.

RESULTS For only seven of the nine animals did the cannulae run successfully throughout the infusion period, and one animal struggled appreciably throughout the later half of the infusion thus invalidating oxygen consumption response relative to the drug. These three animals were excluded from the analyses. Results are shown in Table 34.

Minimum metabolic rate in this case was defined as the average of the three, consecutive minute oxygen consumption readings prior to

TABLE 34

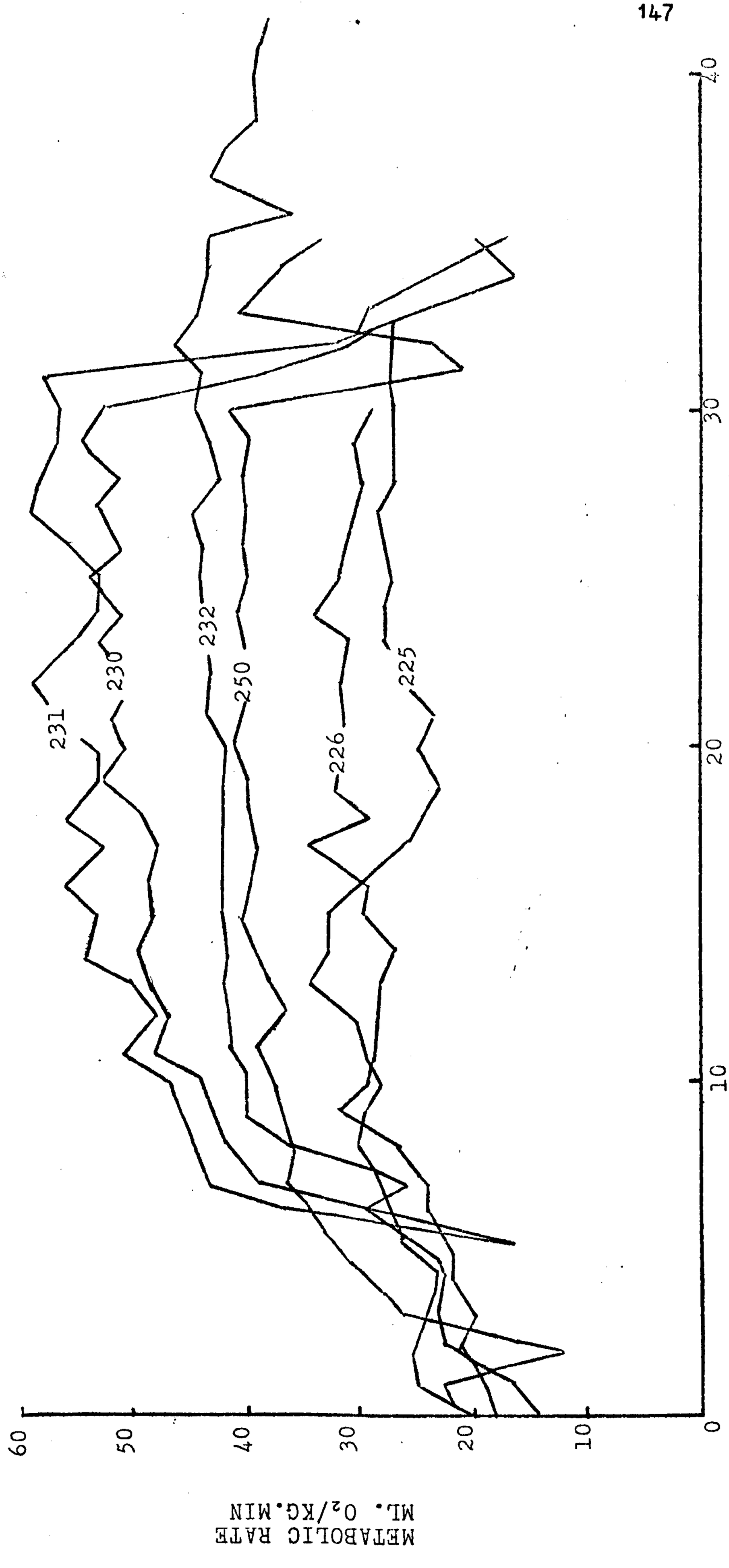
RESPONSES TO I.V. NORADRENALINE IN BLACKFACE LAMBS

LAMB IDENTITY	SEX	AGE (HRS)	WEIGHT (KG)	MINIMUM 1 METABOLIC RATE ML.O_2/ KG.MIN	MAXIMUM 2 METABOLIC RATE ML.O_2/ KG.MIN	PERCENTAGE INCREASE IN METABOLIC RATE 1 - 2	2 AS A PERCENTAGE OF COLD INDUCED PMR	TIME TO REACH 2 AFTER NA INFUSION START (MINS.)	RESPIR-ATION RATE CHANGE MIN-MAX	RECTAL TEMP. CHANGE °C MIN-MAX
230	F	4.5	3.85	15.4	53.4	x 3.5 24.7	88	27	-256	+2.5
231	F	6.0	2.90	15.4	58.5	x 3.8 28.0	97	27	x 4.8 49 - 236	+2.0
232	M	18.5	4.30	14.7	44.4	x 3.0 20.2	74	25	x 3.1 72 - 224	+1.3
250	F	52.0	3.80	21.4	40.4	x 1.9 9.0	67	26	x 5.0 60 - 300	+2.0
226	M	70.0	4.40	18.5	32.7	x 1.8 7.7	54	22	x 1.7 72 - 122	+0.8
225	M	71.0	3.40	20.6	33.5	x 1.6 6.3	56	13	x 1.4 46 - 64	+0.5

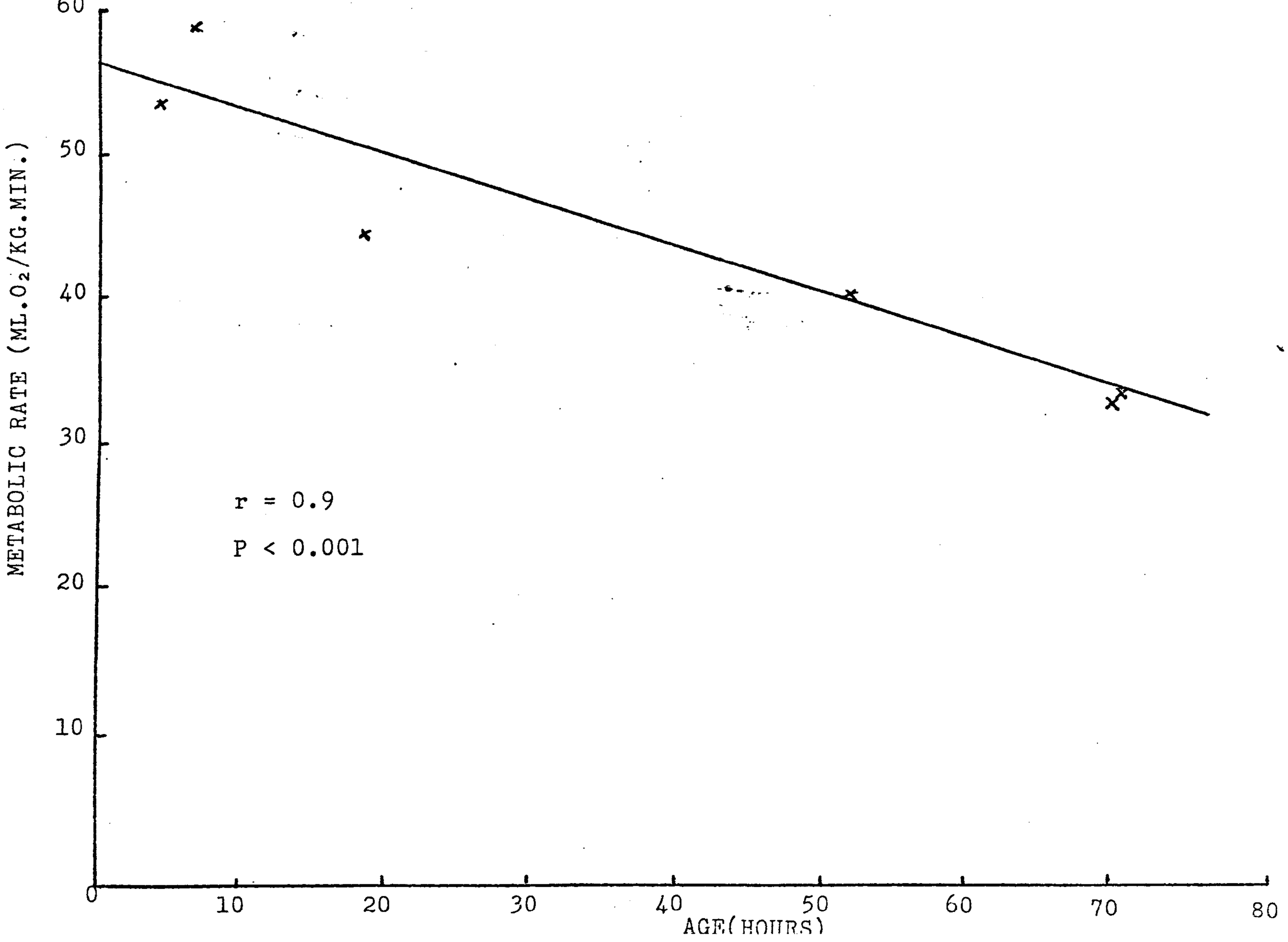
administration of the noradrenaline. In all cases rectal temperature was steady, there was no evidence of hyperventilation or shivering, and no violent movement was observed. There was an approximate five minute delay after administration in thermogenic response to the noradrenaline in all individuals, with the maximum metabolic response occurring around the twenty sixth minute (see Graph I), except in the case of the oldest two animals. This maximum metabolic rate was calculated from the average of the top five consecutive oxygen consumption readings. In all but lamb number 232, metabolic rate had started to decline by thirty minutes, this animal started to struggle around the thirty minute period producing a secondary peak. A decline in metabolic rate was noted later. Respiration rate increased in all cases but to a lesser extent in the two oldest animals. Maximum respiration rates were noted around peak metabolism. Hyperventilation was seen in the younger animals. Rectal temperature increased over the thirty minute period; again the largest increases were noted in the younger animals. Once removed from the calorimeter and dried, the lambs returned to normal pre-test rectal temperature within one hour and were returned to their dams. Only barely warm air was used to dry the hyperthermic lambs to prevent further temperature rise. Maximum metabolic rate levels attained were around ninety percent of that of cold-induced peak metabolic rates for a similar group of Scottish Blackface lambs ($n = 18$) but this percentage dropped towards fifty percent for the older animals.

Graph J shows the relationship between maximum metabolic response to noradrenaline and age. The linear regression is significant $p=<0.001$.

GRAPH I METABOLIC RESPONSE TO NORADRENALINE (5µg/Kg FOR 30 MIN. I.V.) FOR SIX SCOTTISH BLACKFACE LAMBS AGED 4.5 - 71 HRS.



GRAPH J RELATIONSHIP BETWEEN METABOLIC RESPONSE TO I.V. NORADRENALINE AND AGE



DISCUSSION. A degree of technical difficulty was experienced during the procedure, the cannulae being awkward to manipulate whilst the animal was restrained, without affecting metabolic response. For this reason, together with the technical difficulty required to cannulate successfully a large number of lambs, it was thought that subcutaneous injection of noradrenaline might prove a more suitable technique for future experimentation.

Graph K shows the metabolic response for lamb 217, injected subcutaneously compared with another i.v. administered lamb (250) of a similar age. The s.c. injected individual is slower to react to the drug, but reaches a higher maximum metabolic rate before decline after the thirty minute dose. A single injection of 150µg/kg was given under the skin behind the shoulder blades once a base metabolic rate had been established (Thompson and Jenkinson, 1968).

EXPERIMENT 2 A study of the technique of subcutaneous injection of noradrenaline

METHOD. A subcutaneous inter-scapular injection of noradrenaline (150µg/Kg) was administered to each of seven Merino, seven Soay and four Scottish Blackface lambs (0 - 2 days) held at thermoneutral temperature in a waterbath. Oxygen consumption, respiration rate and rectal temperature were recorded as in Experiment 1.

RESULTS. The main aim of the experiment was to examine the technique of s.c. noradrenaline administration rather than provide evidence of breed differences in response.

Results are shown in Table 35 and Graph L. No significant age

GRAPH K COMPARISON OF METABOLIC RESPONSE TO NORADRENALINE S.C. v. I.V. ADMINISTRATION IN TWO SCOTTISH BLACKFACE LAMBS OF SIMILAR AGE

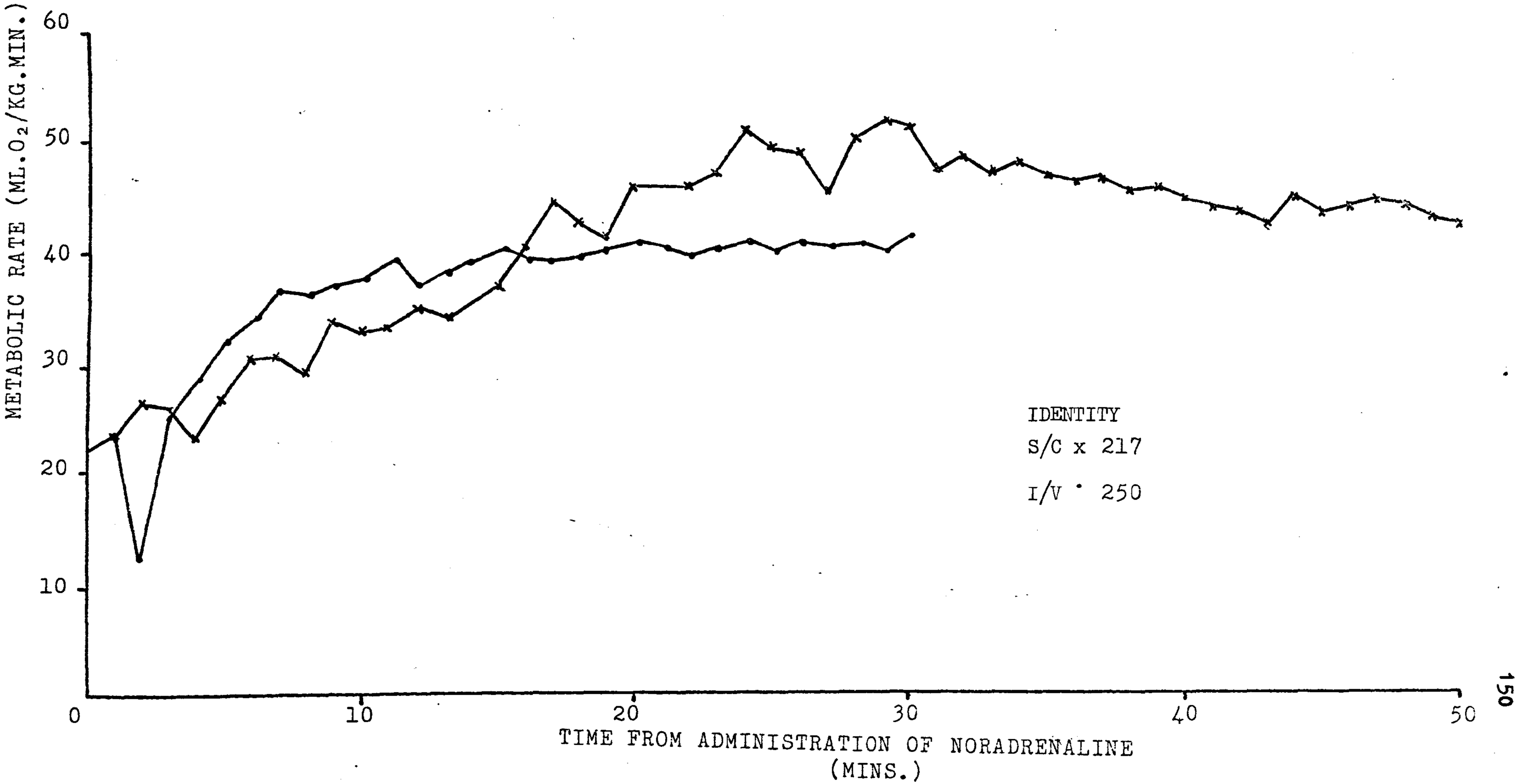
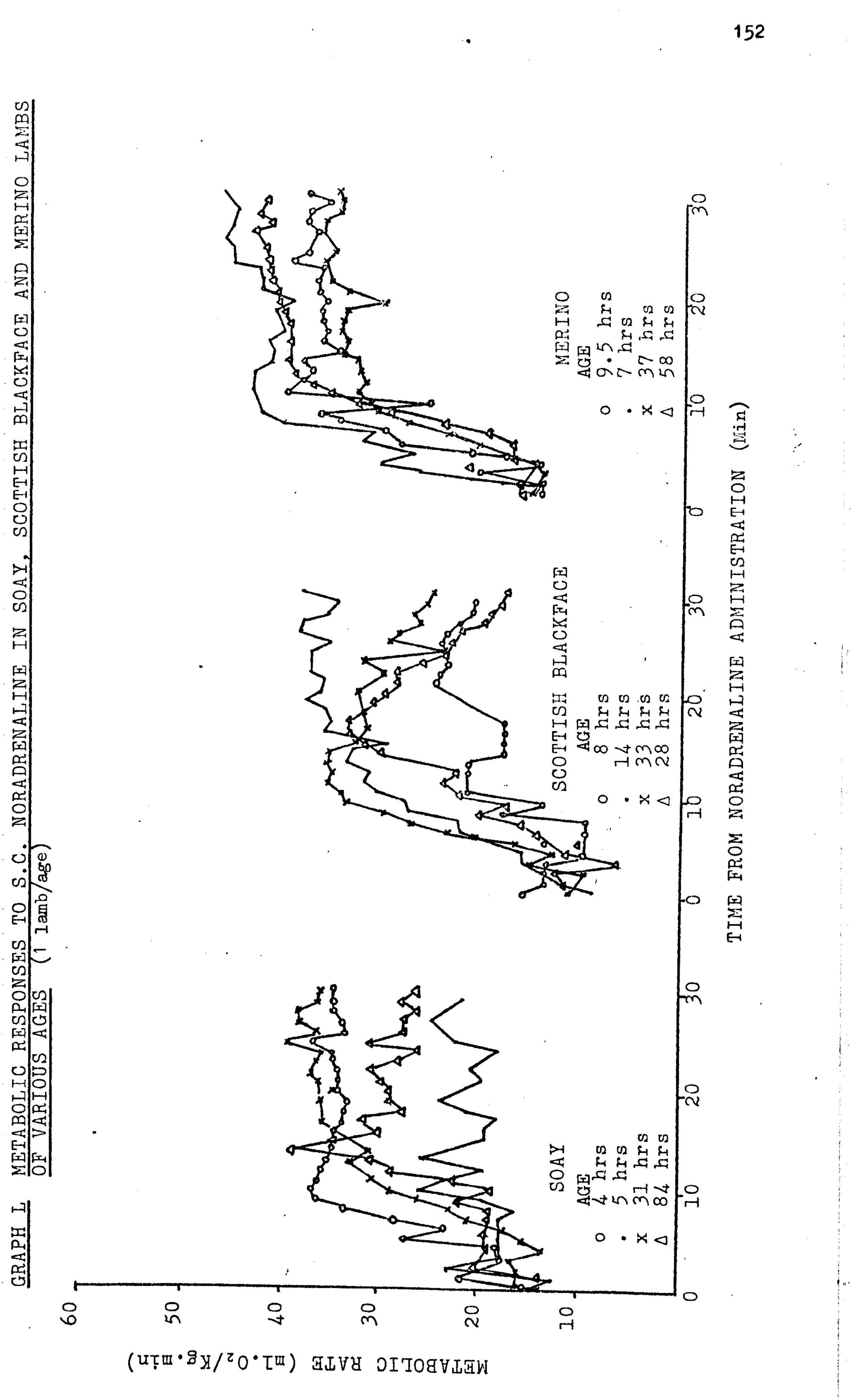


TABLE 35 BREED COMPARISON FOR METABOLIC RESPONSE TO S.C. NORADRENALINE

BREED	AGE	RESPIRATION RATE (MIN. - MAX)	MIN. METABOLIC RATE ML.O_2/KG.MIN.	MAX. METABOLIC RESPONSE ML.O_2/KG.MIN.	TIME OF(MINS) MAX. RESPONSE POST INJECTION
Tasmanian	1.5	48 - 130	8.8	31.4	21
Merino	7.0	44 - 220	14.0	44.9	24
	9.5	52 - 73	14.3	37.1	23
n = 7	21.0	46 - 168	18.5	43.6	22
	23.0	56 - 248	16.4	40.3	23
	37.0	- - -	15.3	35.6	25
	58.0	57 - 120	16.0	41.9	26
Soay	4.0	62 - 168	12.8	36.5 *	9
	5.0	54 - -	16.5	22.8	13
n = 7	12.0	- - -	19.8	47.5	26
	12.5	48 - -	18.5	47.1	27
	13.5	36 - 90	11.5	24.8	28
	31.0	60 - -	15.0	37.6	25
	84.0	39 - 60	14.6	34.6	13
Scottish	8.0	40 - 200	12.3	32.4	26
Blackface	14.0	54 - 250	13.5	36.3	23
	28.0	52 - 256	10.4	23.5	30
n = 4	33.0	54 - 270	10.7	32.4	15

* includes period of struggling

GRAPH L METABOLIC RESPONSES TO S.C. NORADRENALINE IN SOAY, SCOTTISH BLACKFACE AND MERINO LAMBS OF VARIOUS AGES (1 lamb/age)



variation was imposed on the comparison. No significant breed differences were found for metabolic response to noradrenaline. No significant linear regression between age and metabolic rate was recorded in any breed. Metabolic response to s.c. noradrenaline occurred in all individuals challenged. The response pattern of initial rise in metabolic rate followed by a plateauing out was similar to that seen for i.v. administration in Experiment 1. Absolute level of response is difficult to compare between experiments because of the great variation in lambs used in Experiment 2.

DISCUSSION. The number of animals in each group was too small to allow meaningful breed comparison. What is apparent from the experiment is that the technique is both simple and is satisfactory in producing a metabolic response to noradrenaline. It is probably suitable for comparison between groups as differences in response are seen between individuals. Individual response to subcutaneous noradrenaline appears very variable within breed and no age pattern emerged as was the case in Experiment 1. This is probably due to the fact that lambs were not drawn from any coherent group and thus great variation was imposed between individuals especially in terms of environmental temperature experienced prior to testing.

A few animals were challenged with noradrenaline out of the waterbath at room temperature but this proved difficult to control as vigorous thermogenic reactors to noradrenaline were not able to dissipate heat as efficiently as those in the waterbath and hyperthermia ensued. In the case of one Scottish Blackface lamb rectal temperature rose three degrees centigrade during testing.

EXPERIMENT 3. Metabolic response derived from shivering and non-shivering thermogenesis in Cheviot lambs

METHOD. Twenty Cheviot lambs aged 8.5 - 79.5 hours were split into two equal groups. One group was given a standard waterbath cold exposure test as described in the main experiment, but the lambs were removed from the waterbath as soon as summit metabolism was expressed in order to speed up the test procedure. The other group of lambs was given a subcutaneous injection of noradrenaline as in Experiment 2. Metabolic rate was recorded in both cases and a summit value estimated from the average of the top five consecutive readings. Next day the lambs were retested with the procedures interchanged between groups.

RESULTS. Only seventeen of the original twenty lambs were available for retesting on day two of the experiment. Results are shown in Tables 36 A,B,C,D. Mothering-up and health problems prevented three individuals from taking part. The metabolic response to catecholamine and cold stress is plotted against age in Graph M. A significant linear regression ($p < 0.01$) was found between age and metabolic response to noradrenaline across the two tests. No such age relationship was seen in the cold induced metabolic rate data, although mean PMR estimated in the second waterbath was significantly lower than that in the first ($p < 0.01$). In all cases the metabolic response to cold stress was greater than that initiated by noradrenaline. For younger animals (less than 30 hours) the latter was 75 percent of the former, but for older animals (over 60 hours) the percentage was reduced to 50 percent.

TABLE 36A GROUP A SUMMIT METABOLIC RATE ESTIMATIONS FROM WATERBATH COLD STRESS AS FIRST TEST

LAMB IDENTITY	AGE (HRS)	WEIGHT (KG)	SUMMIT METABOLIC RATE (ML O_2/KG.MIN)
25	8.5	3.7	70.9
30	20.0	5.4	68.1
10	22.0	4.25	73.1
34	24.0	4.8	74.1
19	25.5	3.7	66.9
11	26.0	5.2	58.3
12	31.5	4.7	75.3
15	34.5	3.45	71.3
33	35.0	5.65	63.7
17	65.0	4.6	63.9
Mean ± SE			68.56 ± 1.71

TABLE 36B GROUP B SUMMIT METABOLIC RATE ESTIMATIONS FROM WATERBATH COLD STRESS AS SECOND TEST

LAMB IDENTITY	AGE (HRS)	WEIGHT (KG)	SUMMIT METABOLIC RATE (Ml O_2/Kg.min)
31	31.0	3.9	59.2
27	37	4.05	72.6
9	48	4.35	63.8
8	49	5.2	62.6
21	86.5	5.5	61.6
18	96	5.1	57.1
13	100	5.85	58.9
16	102	5.1	61.8
14	107	6.95	53.9
Mean ± SE			61.28 ± 1.74

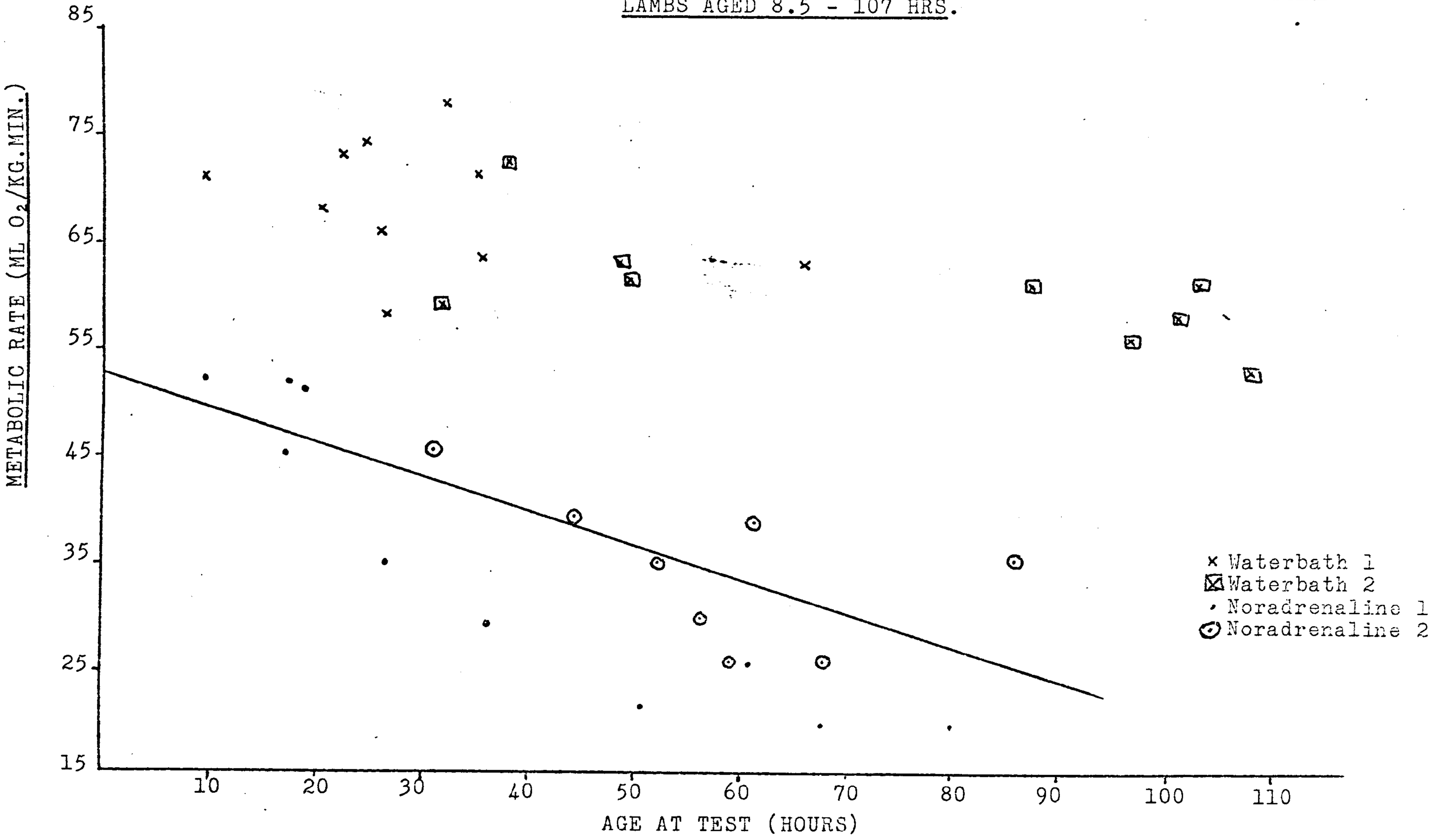
TABLE 36C GROUP B MAXIMUM METABOLIC RESPONSE TO S.C. NORADRENALINE AS FIRST TEST

LAMB IDENTITY	AGE (HRS)	WEIGHT (KG)	RESPIRATION RATE	MINIMUM METABOLIC RATE ML O /KG.MIN	MAXIMUM METABOLIC RATE ML O /KG.MIN	LOCATION OF MAXIMUM RESPONSE (Min after inject.)
21	9.0	4.0	63 - 210	15.4	52.4	13
9	17.0	4.2	80 - 210	15.3	52.3	12
26	17.0	5.7	68 - 282	16.8	45.0	10
8	18.5	4.75	62 - 258	16.1	51.5	12
20	26.5	3.2	56 - 100	13.1	34.4	23
16	36.0	4.6	62 - 96	14.7	29.5	15
13	50.5	5.3	58 -	13.0	21.3	25
14	61.0	6.4	72 - 150	12.7	26.6	19
21	67.5	5.5	60 - 140	13.9	20.2	25
18	79.5	5.1	60 - 84	13.8	20.4	10
Mean					35.45 ± 3.93	

TABLE 36D GROUP A MAXIMUM METABOLIC RESPONSE (AVERAGE OF TOP 3 READINGS) TO S.C. NORADRENALINE AS SECOND TEST

LAMB IDENTITY	AGE (HRS)	WEIGHT (KG)	RESPIRATION RATE	MINIMUM METABOLIC RATE ML O_2/KG.MIN	MAXIMUM METABOLIC RATE ML O_2/KG.MIN	LOCATION OF MAXIMUM RESPONSE (Min after inject.)
25	30.5	4.1	60 - 318	14.3	45.7	9
30	44	5.1	52 - 246	10.3	39.7	10
10	52	4.25	32 - 256	11.3	35.3	15
33	56	5.95	62 - 250	12.9	30.3	9
12	58.5	4.9	50 - 75	11.6	26.2	10
11	61	5.9	60 - 104	14.0	39.3	11
15	67.5	3.7	42 - 80	12.6	26.5	17
17	86	4.5	65 - 204	13.7	35.7	12
Mean						34.84 ± 2.42

GRAPH M COMPARATIVE METABOLIC RESPONSE TO COLD STRESS AND S.C. NORADRENALINE FOR CHEVIOT LAMBS AGED 8.5 - 107 HRS.



DISCUSSION. The relationship between age and metabolic response to noradrenaline was again established as in Experiment 1. The lambs tested here were held under similar environmental conditions prior to and between tests. The lack of age response in Experiment 2 may illustrate the influence of the environment on NST capability.

A small number of individuals in Experiment 3 showed an atypical reaction to noradrenaline administration some thirty minutes after removal from the waterbath. These animals showed muscle spasm and hyperventilation, although rectal temperature was by this time approaching normal pre-test levels. These fit-like episodes ceased after a further 15 - 30 minutes and the lambs were returned to their dams. No abnormal behaviour was noticed in the waterbath. No subsequent health problems were seen in these individuals and the reaction was never noted in any other breed.

Mean metabolic response to noradrenaline injection was similar to that reported for lambs (60 - 132 hours) by Thompson and Jenkinson (1968). In this latter experiment the dose of noradrenaline administered was 400µg/Kg body weight compared with 150µg/Kg as given in this experiment.

Mean base metabolic rate for eighteen of the Cheviot lambs given s.c. noradrenaline either at first or second test was 13.6 $\pm$ 0.39 ml02/Kgmin. This compared with the mean maximum metabolic response to noradrenaline of 35.1 $\pm$ 2.57 ml02/Kgmin ($p < 0.02$) for the same group. Thus the maximum metabolism produced by non-shivering thermogenesis was approximately two and a half times base metabolic rate. Similar values have been returned by Alexander et al (1975), and Jansky (1973).

COLD EXPOSED PRE-PARTUM EWES.

The hypothesis for this set of experiments was founded on a number of observations. Firstly the presence of brown fat in the neonate and its persistance if animals are maintained in a cold environment (Alexander et al, 1968).

The question arose, "Is there any way to influence fat content/metabolism in the neonatal lamb?" Edson, Hudson and Hull (1975) produced evidence for increased fatty acid transfer across the placenta during maternal fasting in rabbits. Fat stores in foetal liver and adipose tissues were increased by 80-100 percent, resulting presumably from elevated maternal FFAs (as a consequence of dam pre-parturient starvation) being shunted across the placenta. Evidence for transfer of fatty acids across the sheep placenta is conflicting (Elphick, Hull and Pipkin 1979; Noble, Shand and Bell, 1979). Natural methods for elevating FFA levels in the ewe and subsequent measurement of FFAs in the neonate do not appear to have been investigated.

Secondly a paper published in an internal report of the Department of Science, University of Edmonton, Canada (Young, Reiche, and Aherne, 1978) showed improved cold tolerance in piglets from sows which had received a cold stress during the latter part of gestation. It was decided to try to reproduce a similar effect in sheep and to monitor various blood parameters before and during cold exposure.

Four experiments were undertaken in 1978 and 1979 with varying degrees of cold stress imposed on the dams during the latter few

weeks of pregnancy in order to elevate pre-partum FFAs. The subsequent progeny together with a control group of lambs were cold stressed in the waterbath.

EXPERIMENT 1. Pre-partum cold exposure of Scottish Blackface ewes, with subsequent cold exposure of their progeny.

METHOD. A group of Scottish Blackface ewes were shorn (5mm) and kept in a climate chamber at 5°C for one month prior to lambing. Another group of control ewes were kept indoors unclipped at a thermoneutral temperature and lambed indoors over the same period. Food was available ad libitum to both groups of ewes. All ewes were weighed at intervals during late gestation and weight changes recorded over the last three weeks of pregnancy. All lambs were cold stressed in the waterbath (standard procedure), half of the control group lambs were fasted from birth and these results are analysed in a further experiment (5). Blood samples, (5ml vacutainers) were taken from the ewes two to three weeks prior to parturition, and from lambs (3ml) after parturition, pre- and post-waterbath test.

RESULTS. Before assessing the results of treatment it should be pointed out that the control group of lambs showed a lower cold resistance time than the average calculated for Scottish Blackface lambs (33) used in the main breed experiment, 52 ± 4.51 mins and 87 ± 7.07 mins respectively ($p < 0.005$). Results for metabolic rates, blood parameters and physical data are shown in Tables 37, 38, 37A and 38A.

Cold resistance (data transformed as in main breed experiment)

TABLE 37 METABOLIC, BLOOD AND PHYSICAL PARAMETERS FOR PRE-PARTUM COLD STRESSED EWES (12) AND THEIR OFFSPRING (20) (1978)

EWE IDENTITY	LAMB IDENTITY	LAMB BIRTH WEIGHT KG	GEST-ATION LENGTH	LITTER SIZE	AGE OF LAMB AT TEST HRS	SKIN THICK-NESS OF LAMBS MM	EWE NEFA µm/l 2 WEEKS PRE-PARTUM	CONDITION SCORE OF EWE	EWE WEIGHT KG CHAN-GE LAST 3 WEEKS OF PREG-NANCY	LAMB BMR MLO_2/KG MIN	LAMB PMR MLO_2/KG MIN	LAMB COLD RES-ISTANCE TIME (MIN) (STRESS CORRECTED C.R.)
5B23	8	3.7	143	2	16.5	3.6	969	2.5	+2.0	17.8	82.3	70 (20)
	9	4.2			18.5	3.3				14.3	78.6	72 (22)
5B36	16	3.7	146	2	21.5	4.3	949	2.25	+1.0	14.4	71.6	81 (27)
	17	3.2			23.0	3.6				15.3	76.2	69 (20)
3B20	18	5.0	148	1	11.5	4.6	887	2.5	+1.5	13.2	55.2	63 (17)
6B25	19	5.0	149	1	22.0	4.7	908	2.5	0.0	16.2	73.2	132(72)
5B20	29	3.0	143	2	6.0	4.0	2112	2.25	+3.0	16.0	46.5	44 (08)
	30	3.1			7.0	3.7				14.6	51.4	43 (08)
5B38	33	3.3	147	2	9.0	4.2	1296	2	+2.0	16.5	75.0	51 (11)
	34	3.1			10.0	4.1				16.2	66.1	61 (16)
3B42	36	4.8	147	2	21.0	4.1	714	2.5	+7.0	13.0	63.7	80 (27)
	37	3.0			23.0	3.8				13.5	58.8	57 (14)
4B7	39	4.3	148	2	18.5	4.5	1724	2	+2.5	11.3	58.6	69 (20)
	40	4.1			20.5	4.2				9.2	67.6	103(44)
2B82	47	4.0	147	2	7.0	4.3	877	2	0.0	13.5	60.8	72 (22)
	48	4.4			9.0	4.3				15.3	59.3	65 (18)
4T427	49	4.5	147	1	8.0	4.3	820	2.5	-0.5	10.2	67.3	90 (34)
3T469	50	6.1	147	1	16.0	5.6	857	2.25	+1.75	10.1	35.9	54 (12)
4T463	51	4.5	149	2	3.5	4.0	296	2.25	-4.0	13.0	58.0	69 (20)
	52	4.1			5.5	4.0				4.7	60.0	50 (10)
Mean ±SE		4.06 ±0.18	146.8 ±0.57		14 ±1.52	4.16 ±0.11	1034 ±137.7			13.4 ±0.69	63.3 ±2.53	70 ±4.68

TABLE 37 A BLOOD PLASMA PARAMETERS FOR LAMBS FROM COLD STRESSED EWES

LAMB IDENTITY	PARTURITION SAMPLE		PRE-TEST SAMPLE		POST-TEST SAMPLE	
	GLUCOSE mM	NEFA µM/l	GLUCOSE mM	NEFA µM/l	GLUCOSE mM	NEFA µM/l
8	0.20	505	4.5	592	3.4	1692
9	0.39	521	4.4	1626	5.1	2011
16	1.1	1593	2.6	-	1.8	2156
17	0.59	945	3.7	-	2.3	1538
18	12.3	2000	6.6	-	13.9	1378
19	1.7	879	0.17	-	8.1	1816
29	0.59	1440	2.8	2264	6.3	2571
30	1.4	1440	4.9	1604	9.4	2440
33	5.3	1220	4.2	813	6.9	510
34	5.1	-	-	-	3.5	1184
36	0.18	802	2.9	1846	5.8	1184
37	0.65	692	1.8	2451	2.2	1184
40	0.11	967	0.26	1153	1.2	-
39	0.11	571	0.20	1264	3.6	1571
47	1.5	1044	2.9	3704	2.5	3209
48	0.01	1022	1.5	1758	6.8	572
49	1.9	901	4.8	1846	12.4	898
50	0.49	198	2.9	225	7.1	-
51	1.1	1220	-	-	-	-
52	-	-	8.3	1769	6.8	1663
Mean ±SE	1.83 ±0.677	998 ±103.9	3.30 ±0.510	1637 ±246.4	5.74 ±0.81	1622 ±172.3

TABLE 38. METABOLIC, BLOOD AND PHYSICAL PARAMETERS FOR CONTROL EWES (9) AND THEIR OFFSPRING (15)

EWE IDENTITY	LAMB IDENTITY	LAMB BIRTH WEIGHT KG	GEST-ATION LENGTH	LITTER SIZE	AGE OF LAMB AT TEST HRS	SKIN THICK-NESS OF LAMBS MM	EWE NEFA µm/l 2 WEEKS PRE-PARTUM	CONDITION SCORE OF EWE	EWE WEIGHT KG CHANGE LAST 3 WEEKS OF PREGNANCY	LAMB BMR MLO_2/KG MIN	LAMB PMR MLO_2/KG MIN	LAMB COLD RESISTAN-CE TIME (MIN) (STRESS CORRECTED C.R.)
3B88	2	3.0	142	2	2.0	3.3	1112	2.25	+0.5	16.5	67.5	60 (15)
	3	3.0			4.0	3.8				10.0	62.5	40 (7)
5B42	4	2.6	143	2	33.0	3.9	918	2.25	-3.0	20.4	52.0	43 (8)
	5	2.8			34.0	3.7				19.1	50.9	36 (5)
6B52	6	3.3	143	2	29.0	4.2	653	2.25	+0.5	12.7	64.1	51 (11)
	7	3.4			30.5	4.2				13.2	57.8	79 (26)
5B58	10	4.2	144	2	19.0	4.0	1102	2.25	+0.5	17.5	44.3	41 (7)
	11	2.3			20.5	3.3				14.7	52.3	37 (6)
5B13	12	3.9	146	1	3.5	4.3	765	2.25	+1.0	13.4	43.5	52 (11)
4S262	20	3.6	144	2	33.0	4.5	347	2.25	+3.5	18.1	60.4	65 (18)
	21	2.6			34.5	4.2				9.6	53.2	37 (6)
4T248	22	4.2	145	1	12.0	4.8	184	2.25	+5.0	12.9	61.4	92 (35)
3B76	31	3.2	145	2	32.0	4.7	949	2.25		13.6	60.4	36 (5)
	32	4.1			33.0	4.5				14.8	56.1	43 (8)
5B35	42	4.1	142	1	38.5	4.9	1439	2.5		13.5	48.6	70 (20)
Mean		3.35	143.8		24	4.15	830			14.7	55.7	52
±SE		±0.08	±0.46		±3.30	±0.13	±130.8			±0.81	±1.85	±4.51

TABLE 38.A

BLOOD PLASMA PARAMETERS FOR LAMBS FROM CONTROL EWES

LAMB IDENTITY	PARTURITION SAMPLE		PRE-TEST SAMPLE		POST-TEST SAMPLE	
	GLUCOSE mM	NEFA µM/l	GLUCOSE mM	FFA µM/l	GLUCOSE mM	FFA µM/l
2	0.7	-	4.7	1956	3.7	255
3	0.7	164	1.9	-	-	-
4	0.03	857	4.1	2176	6.2	1154
5	0.08	2484	4.0	654	9.0	1044
6	0.8	572	4.7	-	7.3	1385
7	0.03	867	4.1	1011	4.9	1071
10	0.05	1341	3.8	470	5.8	969
11	0.10	1462	2.7	-	5.0	1418
12	0.02	1473	11.9	1670	-	-
20	0.9	670	3.6	1121	11.5	879
21	0.44	428	4.8	725	3.7	1165
22	1.1	1121	-	-	2.7	1571
31	0.03	747	3.8	152	9.1	939
32	1.9	846	3.7	549	-	-
42	1.6	802	1.5	266	13.9	-
Mean ±SE	0.56 ±0.157	988 ±152.8	4.24 ±0.65	977 ±206.5	6.9 ±0.98	1077 ±105.1

was significantly higher for lambs from "cold" ewes over that of controls ($p < 0.01$). No significant variation in skin thickness was present between the two groups, but lamb birth weight was significantly higher for the lambs from "cold" ewes ($p < 0.01$). Mean gestation length was also greater in "cold" ewes than in controls ($p < 0.002$). No significant correlation was found between lamb birth weight and gestation length. Weight and gestation length relationships will be discussed further in Experiment 4.

Base metabolic rate was not significantly different between treatments but peak metabolic rate is higher for the lambs from "cold" ewes ($p < 0.05$). If lamb number 50 is dropped from the analysis as having an atypical, almost non-reactive, PMR, some 56 percent below the treatment mean, then differences in PMR are significant ($p < 0.005$). The age difference ($p < 0.01$) imposed between treatments, with control lambs having a greater mean age, can be discounted. In the main breed experiment, age was significantly and positively related to PMR but in this case the relationship was reversed.

Ewe plasma non-esterified fatty acid (NEFA) mean levels were greater in the cold group but not significantly so. Lamb pre- and post-test NEFAs are different ($p < 0.05$) between groups with those from "cold" ewes being highest. No significant variation was found for either plasma NEFA at parturition or plasma glucose at parturition or pre- and post-test samples. The high standard errors recorded in Tables 37A and 38A reflect the great variation between individuals of the same group.

Plasma glucose levels rose between parturition and pre-test samples ($p < 0.001$) for control lambs but not for those from cold

stressed ewes. A significant rise occurred between pre- and post-test glucose levels for lambs from "cold" ewes ($p < 0.02$) and in controls ($p < 0.05$).

No significant changes occur for NEFA between the three samples for individual lambs except in the case of the lambs from cold stressed ewes where levels increased significantly ($p < 0.01$) between parturition to pre-test.

CONCLUSION. Advantages in cold resistance and possibly PMR capability can occurr in lambs from ewes which have been cold exposed during pregnancy.

Blood sampling using vacutainers on lamb jugular veins was difficult due to the fine and flaccid nature of the blood vessels of the neonates. For this reason the stress imposed on the animals during blood sampling was thought possibly to have some influence on the validity of blood analysis results. Recourse to cannulation was considered for future experiments to alleviate this situation.

Experiments 2 and 3 were attempts to investigate the nature of the cold stress applied to the ewe to produce these offspring effects. Both experiments were affected by technical difficulties but are included for the sake of completeness.

EXPERIMENT 2. The effect of pre-partum cold exposure of ewes on the cold resistance of their offspring using natural cold exposure.

An attempt was made to reproduce the results obtained in Experiment 1 for increased cold resistance and possibly peak metabolic rate for lambs from ewes subjected to a pre-partum cold exposure. In this experiment the cold stress imposed was both variable and less severe (except for isolated instances of cold weather at night).

Method. The progeny of two groups of draft ewes (from different home farms) were cold stressed in the waterbath. Half of each group of ewes were clipped about three weeks prior to lambing. Experimental design took account of different sire groups within the dam pool. All ewes (controls and clipped) ran outside. Single ewe blood samples were taken at parturition.

Repeat waterbath tests were carried out on nineteen of the tested lambs, nine being kept in cold ($2^{o}C$) between tests and ten in warm (inside).

RESULTS. Results are given in Table 39. No significant difference was found for PMR and cold resistance between controls and lambs from cold ewes either at first or repeat waterbath after lambs were kept in warm or cold conditions.

CONCLUSION. It was concluded that the cold treatment given in this experiment was not extreme or constant enough to produce similar variation in progeny between ewe treatments as in Experiment 1. The draft ewes in this experiment were not themselves in very good condition. A number of problems arose with ewe milk supplies drying up and consequent rejection of lambs and ewe condition scores were low in several instances.

TABLE 39 WATERBATH COLD RESISTANCES AND METABOLIC RATES OF LAMBS FROM CONTROL AND PREPARTUM COLD STRESS DRAFT EWES

LAMBS FROM COLD STRESSED EWES				LAMBS FROM CONTROL EWES			
LAMB IDENTITY	AGE	COLD RESISTENCE (MIN)	PEAK METABOLIC RATE ($MLO_2/KGMIN$)	LAMB IDENTITY	AGE	COLD RESISTANCE (MIN)	PEAK METABOLIC RATE ($MLO_2/KGMIN$)
1	4.5	54	51.2	2	24.0	47	60.8
5	23.0	63	55.1	3	25.0	44	61.5
6	24.5	88	72.6	7	30.5	54	63.7
11	31.0	94	67.0	8	32.0	54	64.0
13	33.0	47	56.9	4	44.5	64	55.0
14	34.5	59	57.9	9	29.0	96	63.8
21	53.0	61	53.6	27	10.0	72	57.0
37	20.0	69	68.3	28	65.0	63	49.3
42	7.5	71	60.8	38	17.0	47	70.4
44	19.5	84	67.0	39	18.0	49	64.9
45	28.0	81	59.8	36	53.0	43	45.8
48	28.5	79	57.4	47	41.0	96	67.8
49	30.0	50	54.4	40	56.0	103	63.6
52	58.5	37	49.0	43	78.5	84	53.9
53	59.5	45	58.4	51	53.0	55	61.9
56	4.5	73	62.0	54	11.5	68	68.5
				10	31.0	69	62.8
				57	15.0	52	51.5
				55	83.0	61	67.6
Mean ±SE	29 ±4.24	66 ±4.18	59.5 ±1.64		37.5 ±5.03	64 ±4.24	60.7 ±1·57

EXPERIMENT 3. Pre-partum cold exposure of Finn Dorset ewes using natural cold.

At the end of 1978 new data logging equipment was introduced into the calorimetry system, the old system having caused much problem during the latter half of the season. A small experiment was devised to test out the new system prior to the main 1979 lambing season. Twenty four Finn Dorset ewes (21 of which were batch mated to lamb between 15 - 20 January) were available to test. After several trial runs, thirteen ewes were available for a pre-partum cold ewe exposure experiment. Eight of these ewes were clipped three weeks pre-parturition. It was intended for the "cold" ewes to remain outside whilst the controls were housed, but both groups had to be housed for one week of particularly severe weather. The progeny of both groups were cold challenged in the waterbath.

RESULTS. Results for cold resistance and metabolic rate are shown in Table 40. No significant difference for lamb birth weight was found between control lambs and lambs from cold stressed ewes. Cold resistance and BMR are significantly different ($p < 0.05$) between groups, cold lambs having higher BMR and greater cold resistance. No significant differences are recorded for PMR.

CONCLUSION. The new data logging system proved very successful.

The results from this experiment confirm those from Experiment 2 in that the cold stress applied to the pre-parturient ewe must be constant over a period to allow differences in cold tolerance of their offspring to be manifest.

TABLE 40 RESULTS OF WATERBATH COLD STRESS ON PROGENY OF FINN DORSET (9 CONTROL AND 15 COLD STRESS) EWES

CONTROL LAMBS (n = 9)						LAMBS FROM COLD STRESSED EWES (n = 15)				
NO.	AGE (HRS)	WEIGHT KG	PMR MLO_2/KGMIN	BMR MLO_2/KG MIN	COLD RESISTANCE (MIN)	AGE (HRS)	WEIGHT KG	PMR MLO_2/KGMIN	BMR MLO_2/KGMIN	COLD RESISTANCE (MIN)
1	8	3.75	52.0	13.6	44	4.5	3.45	65.2	14.8	61
2	12	3.1	57.0	15.4	37	6.5	2.8	62.7	17.7	58
3	20.5	4.9	57.2	17.4	52	10.5	3.8	51.3	15.4	46
4	29.5	3.25	43.3	8.0	41	12	3.3	60.3	15.5	47
5	26	3.75	58.0	13.5	48	13	3.6	68.3	16.6	48
6	38	4.4	61.4	15.0	67	15	3.6	49.2	16.7	44
7	39	4.4	63.1	16.4	41	16.5	3.6	53.8	17.9	37
8	64.5	3.6	55.0	9.6	44	19	2.75	59.5	15.3	59
9	65.5	3.1	55.2	13.5	47	20.5	3.15	57.1	10.4	62
						27	3.2	60.9	17.3	71
						28.5	4.05	65.6	15.2	68
						30	2.4	63.8	16.3	50
						32	4.1	59.6	15.4	61
						33	3.1	82.2	20.8	54
						96	4.0	54.4	16.1	58
Mean	34	3.8	55.8	13.6	47	24.27	3.39	60.9	16.1	55
±SE	±6.86	±0.21	±1.92	±1.02	±2.92	±5.65	±0.13	±2.1	±0.57	±2.44

EXPERIMENT 4. Controlled pre-partum cold exposure of Scottish Blackface ewes with subsequent NEFA sampling (by umbilical catheterisation at birth) in their offspring during waterbathing.

Objectives: To study the effect of cold exposure during pregnancy under more carefully controlled conditions than in Experiment 1.

Four batches of ewes were clipped (5mm) and held in a controlled temperature climate chamber at 1°C for five weeks immediately pre-partum. An equal number of unclipped control ewes were housed for an equivalent period. All ewes were fed ad libitum. In total twenty six ewes, thirteen control and thirteen clipped produced twenty four and twenty lambs respectively for testing in the waterbath. A careful watch was kept on near term ewes and once the first signs of parturition were observed the ewes were brought out of the chamber and bedded on newspaper to minimise lamb infection. All litter was burned after use.

Non-surgical umbilical vein catheterisation of lambs was carried out aseptically immediately post-partum and before the newborn lamb was delivered to the ground. The lambs were removed to the laboratory for this procedure, the umbilical cord being cut at about four inches. The cord was clamped at the tip with artery forceps to prevent contraction of blood vessels into the umbilicus. The membrane sheath was cleaned with hibitane solution and split longitudinally to reveal the number of vessels. The vein was selected and clamped at the tip; a small nick in the vessel wall was made just above the clamp. An infant's umbilical catheter (Portex Ltd.) was inserted into the vein to a depth of about eight

centimetres and was secured with black silk suture. The catheter was flushed with heparinised saline and a 3ml blood sample was taken. The catheter was reflushed with saline, sealed and held in place with a crepe bandage around the lamb's abdomen. At this stage the lamb was returned to its dam to be cleaned and fed by the ewe. The whole procedure took less than five minutes.

Waterbathing procedure was as for the main breed experiment except that blood samples were taken at base, and at summit metabolism and after the animal was removed from the bath and had recovered temperature. Lambs were removed from the bath once summit metabolism had been passed and in general temperature recovery was rapid.

The taking of blood samples and adjustment of non-functioning cannulae whilst the animals were immersed in the water did not result in any appreciable metabolic activity as had been the case with the jugular cannulations in the i.v. noradrenaline experiment; animals remained undisturbed by the procedures. After the waterbath procedures catheters were removed and the blood vessels tied off. Great aseptic care was taken during catheterisation and after immersion in water. Lambs were watched intensively for a few days after treatment. No health problems were encountered, Streptomycin was given routinely at first but this practice was later discontinued.

RESULTS. Physical data, blood parameters and metabolic rate results are given in Tables 41 and 42. Pre-partum NEFAs were significantly elevated in the "cold" stressed ewes ($p < 0.01$), mean values being 608 ± 134 for controls and 1214 ± 726 for "cold" ewes.

TABLE 41 COLD RESISTANCE, METABOLIC RATE AND FREE FATTY ACID PLASMA LEVELS FOR 24 LAMBS FROM CONTROL EWES

EWE IDENTITY	LAMB IDENTITY	BIRTH WEIGHT KG	GESTATION LENGTH (DAYS)	EWE WEIGHT CHANGE OVER LAST 3 WEEKS OF PREGNANCY KG	BASE METABOLIC RATE (MLO_2/KG MIN)	PEAK METABOLIC RATE (MLO_2/KG MIN)	LAMB NEFA M/L			
							BIRTH	BASE	POST-SUMMIT	RECOVERY
7D53	14	3.0	145	+4.5	11.0	57.5	+			
	15	3.2			14.1	86.7	+			
7D61	16	3.6	144	+5.0	9.4	54.5	+			
	17	3.2			20.0	73.8	+			
5B35	18	3.7	146	+3.25	14.5	50.7	1921	892	1933	1989
	19	2.5			15.2	47.4	2293	1009	2123	2751
7D93	20	2.5	145	+3.0	14.8	42.9	1568	1509	2056	1799
	21	3.1			13.6	49.8	1478	3684	4132	4303
2B7	25	4.4	146	-0.5	8.9	59.3	637	1626	1646	1742
	26	4.0			12.5	65.7	823	1646	1799	1875
4S231	32	2.5	149	+5.75	10.3	60.6	1823	1921	1771	2189
	33	2.8			8.7	56.2	1117	1519	1504	2161
3T469	40	4.1	148	+7.0	12.9	50.2	862	1097	1961	2208
	41	3.1			15.4	44.1	1431	3195	2523	3332
2S198	48	2.7	148		7.8	66.6	1185	1607	1456	2027
2A132	49	3.9	148		13.1	46.1	960	2979	2989	3875
4B7	50	2.9	142	+4.0	7.0	58.9	1636	980	1646	1504
	51	2.9			10.9	55.3	1450	2009	1152	2856
5B38	52	3.5	144	+3.0	6.9	40.3	1264	1166	1152	1646
	53	3.0			8.5	49.5	989	2489	1323	1742
7D44	66	3.4	148	+0.5	15.4	57.4	4604	3263	3646	1913
	67	3.0			*	*	941	1558	1761	1447
4T248	69	4.5	146	+5.0	12.5	58.3	627	3047	3608	1714
	70	3.2			14.3	47.6	745	2803	1247	2523
Mean		3.28	146.08		12.1	55.6	1417	2000	2071	2280
±SE		±0.12	±0.57		±0.69	±2.20	±196	±197	±195	±175

* No metabolic response to cold
\+ No blood samples

TABLE 4.2 COLD RESISTANCE, METABOLIC RATE AND FREE FATTY ACID PLASMA LEVELS FOR 20 LAMBS FROM 15 COLD EXPOSED EWES

EWE IDENTITY	LAMB IDENTITY	BIRTH WEIGHT (KG)	GESTATION LENGTH (DAYS)	EWE WEIGHT CHANGE OVER LAST 3 WEEKS OF PREGNANCY (KG)	BASE METABOLIC RATE (MLO_2/KG MIN)	PEAK METABOLIC RATE (MLO_2/KG MIN)	LAMB NEFA µM/l			
							BIRTH	BASE	POST SUMMIT	RECOVERY
4T427	1	3.9	144	+8.0	*	*	-	-	-	-
4T423	2	4.0	145	+4.0	13.8	49.8	1872	5772	4903	7235
4T242	5	4.0	146	+11.5	10.9	44.3	1489	3381	-	-
5B23	6	3.2	147	-2.5	8.0	58.9	421	2753	1818	1771
	7	3.3			6.0	55.5	1362	1029	1961	1752
4T335	8	4.8	147	+4.0	13.4	50.0	1479	2205	4693	6188
6B13	9	4.7	148	+3.25	5.9	36.4	1245	4978	3142	3189
4S446	10	3.9	148	+12.5	7.7	46.1	989	2107	4923	5921
	11	3.3			10.6	48.9	1185	4116	2285	4617
5B52	12	3.1	150	-1.5	4.1	43.1	+			
	13	3.5			7.0	56.5	+			
2A36	57	3.7	146	+2.5	13.2	53.4	558	1038	1818	3313
	58	3.0			12.5	58.5	588	3675	2361	2922
2T109	59	3.8	146	+0.5	12.9	44.6	1431	5066	4703	4312
2T278	60	3.6	146	+0.75	13.4	54.9	480	4439	2418	2399
	61	2.4			15.6	59.4	1343	3929	2218	2789
7D74	62	3.5	149	+0.75	11.1	51.4	1185	2998	2237	2246
	63	3.2			13.4	58.6	1294	3067	1818	2532
7D17	64	4.0	148	+3.75	9.8	48.8	1784	4096	2246	4950
	65	4.2			13.2	38.6	1479	3410	2046	2485
Mean ±SE		3.66 ±0.13	146.92 ±0.46		10.7 ±0.76	50.4 ±1.59	1187 ±106	3415 ±323	2849 ±302	3664 ±420

*no metabolic response to cold

+ no blood samples

No significant differences were recorded between groups for lamb metabolic rate either at base or peak. Lamb NEFAs were not different between groups at parturition but those estimated at base metabolism ($p < 0.001$) and recovery ($p < 0.001$) were significantly higher in the lambs from "cold" ewes. Post summit estimates were slightly higher in lambs from "cold" ewes ($p < 0.05$). Birth weight differences were just significant ($p < 0.05$) but the gestation length difference was not significant. Gestation and birthweight data were then pooled with that from the 1978 Scottish Blackface experiment (Experiment 1), t tests are shown in Table 43.

The effects of pre-partum cold exposure of ewes on birth weight and gestation length are discussed in two later papers. No sire, dam or litter size effects were found for gestation length and average litter weight was not related.

CONCLUSION. Cold resistance is significantly increased in lambs from pre-partum cold stressed ewes (only measured in Experiment 1). Any slight influence on metabolic rate between groups was not confirmed in the second year of the experiment.

The differences in NEFA levels, slightly higher pre- and post-test for the lambs from the "cold" ewes in 1978 were confirmed in the 1979 experiment where blood sampling technique was much improved. No differences were recorded at parturition perhaps because of other stresses associated with the birth process. Levels of glucose and NEFA concentration increased from base/pre-test samples to post-summit/post test for both groups of lambs. Similar rises were recorded by Alexander, Mills and Scott (1968).

EXPERIMENT 5. Waterbath exposure of Scottish Blackface lambs

TABLE 43 SIGNIFICANCE OF VARIATION FOR TREATMENT BREED MEANS FOR LAMBS FROM CONTROL AND PRE-PARTUM COLD STRESSED EWES. 1978 + 1979 SCOTTISH BLACKFACE DATA POOLED.

VARIABLE	MEAN ± SE		t	SIGNIFICANCE OF VARIATION BETWEEN CONTROL AND COLD TREATMENT MEANS
	(n) CONTROL	COLD		
GESTATION LENGTH (days)	(22) 145.14 ± 0.45	(25) 146.84 ± 0.35	3.0	$P < 0.005$
LAMB BIRTHWEIGHT (KG)	(39) 3.31 ± 0.09	(40) 3.86 ± 0.12	3.66	$P < 0.001$

fasted for four hours post partum.

Objectives: Since in many of these experiments the extent to which lambs had suckled prior to test was not known precisely, it was important to evaluate the extent to which feeding might influence test results.

METHOD Fifteen Scottish Blackface lambs from control ewes in Experiment 1 were fasted for approximately four hours immediately post-partum. The lambs were waterbathed and blood sampled as for Experiment 1. A comparison was made with other lambs from the control group which were allowed to suckle and cold stressed in Experiment 1.

RESULTS. Results are given in Table 44. Base metabolic rate from fasted lambs was significantly lower than for lambs from control ewes ($p < 0.001$). No difference was found for peak metabolic rate, but cold resistance was significantly higher in fasted lambs ($p < 0.005$). Plasma glucose levels were significantly lower in fasted lambs both pre- and post-cold stress ($p < 0.001$). No difference was recorded for parturition samples. NEFA levels are significantly higher for fasted lambs post waterbath test ($p < 0.01$) but no significant difference was found for the parturition or pre-test samples.

CONCLUSIONS As no individual was waterbathed without ensuring it had been suckled to some degree by the dam the slight differences between fed and unfed lambs found here are not likely to have influenced the results of the experimentation to any appreciable degree. Mercer (1974) records low BMR for lambs starved from birth

TABLE 44 PHYSICAL AND METABOLIC DATA FOR 15 COLD STRESSED SCOTTISH BLACKFACE LAMBS FASTED FOR FOUR HOURS AFTER BIRTH

LAMB IDENTITY	AGE	BIRTH WEIGHT (KG)	SKIN THICK-NESS (MM)	BMR (MLO_2/KG MIN)	PMR (MLO_2/KG MIN)	COLD RESIS-TANCE (MIN)	BLOOD PARAMETERS					
							PARTURITION		PRE-TEST		POST-TEST	
							GLUCOSE mM	NEFA µM/l	GLUCOSE mM	NEFA µM/l	GLUCOSE mM	NEFA µM/l
13	3.5	2.7	3.4	10.4	66.0	56	0.44	2378	0.87	704	3.3	1868
14	5.0	3.1	3.9	5.3	59.5	68	0.71	560	0.32	452	3.4	1724
15	5.5	4.4	4.1	19.8	62.7	79	0.28	242	-	-	12.9	2164
23	4.0	3.5	3.9	9.0	42.4	52	0.08	1923	0.04	2516	0.58	1255
24	5.0	3.4	4.1	7.5	51.2	75	0.28	1407	0.04	1560	4.6	1495
25	4.0	4.2	4.4	7.9	48.2	68	1.5	1209	1.2	776	1.8	2473
26	4.0	3.8	4.6	6.7	55.7	128	0.04	2088	0.23	408	8.3	1626
27	3.0	4.5	4.0	7.7	48.0	103	1.0	912	-	-	3.8	1184
28	5.0	4.0	4.1	5.7	52.0	95	0.11	1429	0.22	692	1.9	2044
35	6.0	3.8	4.9	11.6	66.1	94	1.0	-	-	-	6.1	1367
38	4.0	3.7	4.1	10.6	61.1	57	0.05	2220	-	-	3.6	796
43	5.0	3.9	5.0	7.8	46.5	38	0.42	1209	0.58	-	4.1	-
46	2.5	3.3	4.1	11.8	58.6	63	0.10	-	0.07	2046	0.13	-
53	3.0	4.5	4.9	4.7	53.8	125	-	1352	-	-	7.0	918
54	4.0	5.6	4.7	8.3	41.6	57	2.2	-	-	-	6.1	1929
Mean	4.25	3.9	4.3	9.0	54.2	77	0.59	1411	0.39	1144	4.51	1603
±SE	±0.26	±0.18	±0.12	±0.95	±2.07	±6.88	±0.171	±189	±0.14	±281	±0.84	±137

Compare with Table 38 for control values

for seventeen hours as a consequence of there being no postnatal rise for BMR. In a longer term fasting experiment Alexander (1962a) demonstrated a substantial decline in summit metabolism for fasted lambs.

DISCUSSION.

Evidence from various experiments where sheep have been housed or exposed to cold pre-partum have yielded conflicting results. Winfield Brown and Lucas (1968) record no effect on lamb birth weight even when feed regime was supplemented. At the other extreme Shelton (1964) showed high temperature during gestation to reduce significantly lamb birth weight, with a consequent increase in mortality.

The current vogue of shearing pregnant ewes while housed has received much attention in both the farming and academic press (Austin and Young, 1977; Cardell, 1979; Maund, 1978; Vipond, 1978). Housing ewes has the advantage of reduced labour costs at lambing and in some cases lambs of heavier birth weight are produced. Shearing has the effect of reducing heat stress on the housed ewe so reducing her maintenance requirements and alleviating the effects of heat stress on the foetus. Without knowing what is the optimum temperature for housed, unclipped pregnant ewes it is not easy to determine whether cold exposure and/or clipping is itself positively beneficial in producing heavier or more viable lambs, or whether it achieves its advantage solely by alleviating heat stress.

HETEROSIS.

A preliminary comparative study of cold resistance and metabolic rate responses to waterbath cold stressing for Scottish Blackface, Cheviot and Scottish Blackface cross Cheviot lambs. It is known that characteristics relating to survival and "livability" are sensitive to the effects of inbreeding (Wiener, 1975) and so it seems possible that effects of heterosis might be detectable in a small trial.

METHOD. A total of twenty four lambs, twelve from each of the breeds listed above were given a standard waterbath cold stress. Lambs were selected for testing to fit into a continuous age distribution of each breed ranging from 0 - 48 hours. All lambs were tested within a three week period in March 1979. Wool samples were taken from Cheviot and Scottish Blackface cross lambs over a square 40 x 50mm from the midside and wool weights determined. The lambs were born outside and held in unheated shelter until tested.

RESULTS. Results are quoted in Tables 45A, B, C. No significant breed variation was imposed on the experiment for age, weight and skin thickness at test. Sex ratios were not extreme in any breed. The crossbred lambs were represented by a greater number of singletons than the two pure breeds.

Fleece depth was significantly associated with breed, Scottish Blackface having the longest coat and Cheviots the shortest. Wool sample weights were compared between the three breed groups with a Scottish Blackface estimate of 0.86 $\pm$ 0.06g/2000mm based on mean values for forty nine individuals sampled in 1978. Mean wool weight

TABLE 45A PHYSICAL CHARACTERIS TICS AND METABOLIC RATE AND COLD RESISTANCE RESULTS AFTER WATERBATHING FOR 12 CHEVIOT LAMBS

IDENTIFY	AGE (HRS)	WEIGHT (KG)	LITTERSIZE	SKIN THICKNESS (MM)	WOOL WEIGHT g/2000MM^2	FLEECE DEPTH (CM)	SEX	COLD RESISTANCE (MIN)	PEAK METABOLIC RATE ($ML O_2/KGMIN$)
7	2	4.1	1	4.14	0.44	1.1	M	96	52.99
8	2.5	4.25	1	4.34	0.68	1.5	M	95	52.94
9	8	2.50	2	3.10	0.42	0.8	M	90	77.58
10	10	2.75	2	2.98	0.38	0.8	F	110	65.45
1	12	3.20	2	4.06	0.74	1.8	F	107	63.28
2	14	3.85	2	3.85	0.57	1.5	M	109	71.66
5	18	3.9	2	4.18	0.77	1.2	F	114	69.23
12	20	2.95	2	3.40	0.40	0.9	M	76	66.10
6	20.5	3.50	2	4.58	0.66	1.2	F	111	65.79
3	20.5	4.4	2	4.32	0.66	1.5	F	173	61.36
11	23	3.9	2	3.56	0.44	1.0	F	76	59.60
14	38	4.45	1	5.26	0.93	1.7	M	115	67.91
Mean ± SE	15.5 ±2.93	3.65 ±0.19		3.98 ±0.19	0.59 ±0.05	1.25 ±0.10		106 ± 7.26	64.49 ±2.06

TABLE 45 B PHYSICAL CHARACTERISTICS AND METABOLIC RATE AND COLD RESISTANCE RESULTS AFTER WATERBATHING FOR 12 SCOTTISH BLACKFACE LAMBS

IDENTITY	AGE (HRS)	WEIGHT (KG)	LITTERSIZE	SKIN THICKNESS (MM)	FLEECE DEPTH (CM)	SEX	COLD RESISTANCE (MINS)	PEAK METABOLIC RATE (ML O_2/KG MIN)
30	0.5	3.9	2	3.52	1.8	M	155	50.8
23	0.75	2.45	1	3.50	1.7	F	49	48.9
22	2.5	4.10	2	4.40	2.0	M	68	55.6
29	4.0	4.40	2	3.94	2.4	M	146	51.1
28	4.5	3.8	1	3.92	2.1	F	88	62.3
36	6.0	4.5	2	4.48	2.5	M	140	53.7
27	9.0	2.5	1	3.76	1.6	M	34	54.3
37	9.0	3.9	2	4.94	2.2	M	121	64.5
31	13.5	3.5	1	3.78	2.2	F	145	68.4
38	17	3.6	2	4.08	1.5	M	124	66.7
34	17.5	3.6	2	3.64	1.9	M	60	60.8
35	19.0	3.3	2	3.88	2.0	F	127	72.7
Mean ± SE	8.5 ±1.93	3.63 ±0.19		3.99 ±0.12	1.99 ±0.09		105 ±12.30	59.15 ±2.26

TABLE 45C PHYSICAL CHARACTERISTICS AND METABOLIC RATE AND COLD RESISTANCE RESULTS AFTER WATERBATHING FOR 12 SCOTTISH BLACKFACE CROSS CHEVIOT LAMBS

-IDENTITY	AGE (HRS)	WEIGHT (KG)	LITTERSIZE	SKIN THICKNESS (MM)	WOOL WEIGHT g/2000MM^2	FLEECE DEPTH (CM)	SEX	COLD RESISTANCE (MINS)	PEAK METABOLIC RATE MLO_2/KGMIN)
23	0.5	3.3	2	4.52	0.66	1.6	F	116	62.70
31	1	4.6	1	4.16	0.69	1.5	M	118	59.50
29	2	4.3	1	4.26	0.78	1.8	M	150	59.30
32	2.5	4.5	1	4.06	0.93	2.0	F	132	64.29
24	3	3.1	2	4.23	0.76	1.2	F	145	66.79
28	8.5	4.0	1	4.42	1.05	1.7	F	149	61.89
26	11	2.95	1	3.72	0.88	1.5	M	61	56.80
22	15	3.5	1	4.56	0.58	2.0	F	164	71.70
34	15.5	4.3	1	4.28	0.66	1.3	M	83	63.80
25	20	3.75	1	3.70	0.54	2.0	M	102	61.50
35	20	3.2	1	3.88	0.96	1.6	F	151	61.89
49	30.5	4.85	1	4.76	-	1.8	M	132	46.70
Mean	11	3.86		4.22	0.77	1.67		125	61.4
± SE	±2.77	±0.19		±0.10	±0.05	±0.08		±8.88	±1.7

was also greatest in the Scottish Blackface and smaller for the Cheviot. t tests for breed mean differences are shown in Table 46.

No significant breed differences were recorded for either metabolic rate or cold resistance. Linear regressions were fitted for age and PMR for each breed. A correlation of 0.68 ($p < 0.001$) was found for the Scottish Blackface breed, but no relationship was determined for the other two breeds; both these had fewer young animals than did the Scottish Blackface breed.

DISCUSSION. The crossbred lambs deviate from the purebreds in comprising a larger percentage of singletons. This is reflected, although not significantly, in a slight birthweight advantage. Fleece characteristics in the cross lambs are intermediate between the pure breeds both in terms of wool weight and fleece depth. Both these characteristics may have survival advantage.

Waterbath data for the pure breeds compared in this experiment, collected over a three year period, show both Cheviot and Scottish Blackfaces to have high cold resistance (Samson and Slee, 1980). The Cheviot also recorded the highest PMR of ten breeds whereas the Scottish Blackface was near the bottom of the breed rankings for this trait. Although the crossbred appears to show an improvement in fleece characteristics over the pure Cheviot, and the trend in cold resistance is for an improvement over both pure breeds, a greater number of individuals would have to be tested in order to draw conclusions about metabolic and cold resistance parameters.

TABLE 46 - BREED DIFFERENCES IN FLEECE CHARACTERISTICS FOR SCOTTISH BLACKFACE, CHEVIOT AND CHEVIOT X SCOTTISH BLACKFACE LAMBS

BREED	FLEECE DEPTH t	FLEECE DEPTH Significance of Breed mean difference	WOOL WEIGHT t	WOOL WEIGHT Significance of Breed mean difference
Scottish Blackface v. Cheviot	5.55	P < 0.001	4.51	P < 0.001
Blackface v. Scottish Blackface x Cheviot	2.76	P < 0.02	-	NS
Cheviot v. Scottish Blackface x Cheviot	3.31	P < 0.005	2.53	P < 0.02

GENERAL DISCUSSION

An examination of many of the published mortality surveys shows no way of identifying the percentage of lamb pre-weaning deaths resulting from the effects of a cold environment. The indication is, from surveys disclosing post-mortem findings, from sheep farmers comments and from laboratory and field data on cold exposure, that the influence of cold on the neonatal lamb is considerable. Some of the factors involved in the resistance of neonatal lambs to cold have been identified and investigated in this study.

The techniques applied in laboratory tests involving cold exposure are bound in themselves to impose a degree of stress (other than cold) on the animals. Much of the evidence presented here is of a comparative nature and is based on relatively large numbers of tested individuals.

Subjective observations on lambs undergoing waterbath tests do not reveal much overt stress as evidenced by muscular struggling during the course of the cold exposure. The great majority of animals remained quiet and apparently calm throughout the entire procedure. Many lambs were seen to relax and go to sleep in the initial warm water stage. Moreover, mean base metabolic rate was within the normal range, and the introduction of the face mask used in metabolic rate measurements appeared not to raise respiration rate over free breathing levels. The newborn lamb indeed seems a model subject. Attempts at waterbathing older individuals aged five - seven days met with a very different reaction. The lambs seemed more

aware and stronger, metabolic rate readings and cold resistance times were unreliable as the lambs struggled throughout immersion.

Criticism may be made that the tests applied in the laboratory bear little relationship to the field situation. Cold resistance breed rankings produced after waterbath and cold stressing correlate well with data for rectal temperature depression for lambs in the field one hour after birth when an estimate of the effective ambient temperature is taken into account (Slee et al, 1980; Slee, 1977). The major criticism of the waterbath technique is probably the partial negating of the fleece insulation properties as a result of saturation. However, the newborn lamb, with birthcoat soaked in foetal fluids or drenched with rain is probably not too far removed from the waterbath situation. Although fleece type did not show a significant effect on either cold resistance or metabolic rate in the main breed experiment, when two extremes are challenged as in the Welsh Mountain birthcoat comparison experiment, fleece length and density do have a significant effect, even in the waterbath. Water has the advantage, due to its high conductivity. of being a powerful cooling medium so the length of the cold exposure and experimental stress on the individual lamb can be minimised.

The data provided from the tested lambs, encompassed a great deal of variation, both between and within breeds, so allowing some investigation of responses to cold stress. Birth weight for example ranged from 1.4 to 8.8 Kg across all breeds and within-breed variation was generally over more than a two kilogram range. Many of these characteristics are seen to have a significant effect on resistance to body cooling and on heat production, providing information on the factors affecting survival in the cold and data

for the later development of a selection index.

Most importantly skin thickness, as estimated from an average of skin fold measurements of five sites, had a consistent and significant effect on cold resistance times and on the duration of increased metabolic rate around the peak level. This latter estimate of peak metabolism is probably of greater survival value to the lamb than the absolute peak value attainable. The measurement of skin thickness, presumably indicates differences in insulation, and may involve variation in tissue thickness, blood vessel location, follicle development and fleece characteristics.

Breed variation in cold resistance is still evident once all significant factors, body weight, skin thickness, rectal temperature, litter size and day of test have been accounted for.

Possibly of more academic interest is the influence of sex on metabolic rate, female lambs showing higher metabolic rate at both peak and once rectal temperature is depressed. The possible effects of endocrine variation were not studied and no data appears available for sex differences in metabolic hormones, eg: Thyroxine in animals and humans during the neonatal period. Another interesting finding is that multiple birth individuals show better cold resistance than singletons once the data have been corrected for effects of weight and skin thickness etc. Lambs fasted from birth and those from pre-partum cold stressed ewes also apparently show enhanced cold resistance; but these findings must be considered as tentative. Little improvement in absolute values of peak metabolic rate is evidenced in these latter cases over control animals. One reason for improved cold resistance in individuals previously stressed by cold (indirectly) or by fasting could be that stress metabolism involving

for example NEFA mobilisation is already functioning and there is not a delay time in its initiation after the stimulus of waterbath cold stress.

The occurrence of significant effects of "day of test" throughout the analyses of cold resistance and metabolic rate in the main breed experiment indicates the possible importance of environmental influences on the physiological responses of the animals under test. This is illustrated when comparing the breed mean cold resistance for Scottish Blackface lambs from ewes kept inside for four weeks prior to lambing with that of the Scottish Blackfaces in the main breed experiment running outside. Both groups were from the same dam pool, yet the former show a significantly lower cold resistance.

Manipulation of environmental effects was exploited in the pre-partum cold ewe experiment. Here the influence of cold altered ewe gestation length and birth weight, cold resistance and metabolic rate of lambs in some cases.

The mixed breed data available in these experiments were not suitable for measuring the heritability of cold resistance but it might be possible to devise a selection index based on heritability estimates of the important determinant factors in cold resistance as identified in the waterbath testing. Heritability estimates for fleece characteristics are already available and fairly high but for other factors such as skin thickness available estimates are for older animals.

Among the areas identified as being of immediate practical application to the sheep industry is the passive recovery technique as used for some of the lambs after waterbath immersions. Many lambs

in the field are endangered by hypothermia. Temperature recovery using this method could be practised in the field with the aid of a small pen to enclose the ewe and an insulated box. No electricity is required. Milk can be supplemented during the procedure if starvation is implicated. In the case of abandoned lambs the shepherd could merely place the weakened animal in the box and finish his current round, picking up the box and lamb on his way back to the steading. Thus treatment would be immediate.

Another point for conjecture is that temperatures experienced by ewes before lambing could affect the ultimate survival potential of their offspring. Some degree of cold stress on the pre-partum ewe may well aid the offspring if they are later challenged by cold stress.

If a selection index for lamb survival can be expressed it must take account of the following factors. Techniques for assessment of these have been demonstrated in this experimentation.

1. HEAT PRODUCTION.

Lambs must demonstrate good heat production capability from birth, both in terms of absolute levels attainable and the length of time increased levels can be sustained. This means biochemical and physiological maturity at birth. Heat production has been demonstrated, in this experimentation, to be mesurable reasonably easily in a large number of lambs within a relatively short period of time.

The importance of the contribution of non-shivering

thermogenesis should not be forgotten here. NST potential can be estimated satisfactorily in quite large numbers of individuals by the calorgenic responses to noradrenaline challenge.

2. HEAT CONSERVATION.

Lambs should possess good heat conservation properties, these can be assessed by measurements of fleece depth and density and skin fold thickness. Skin biopsies may be useful here if variation can be imposed in fat content of neonatal lambs.

3. BEHAVIOURAL ASPECTS.

Lambs should be capable of purposeful mobility as soon as possible after birth. This is seen to be influenced to some extent by the effect of environmental temperature on the rectal temperature of the lamb. Mobility allows feeding, maternal bonding and avoidance of crushing by the dam in the penned situation.

In conclusion, I should like to refer to a remark made by two sheep farmers at ABRO's Stanhope hill farm open day. They were overheard to say when looking at two sheep in a pen, one with poor and one with good cold resistance "But they both look the same."

APPENDIX 1

TABLE A MORTALITY IN LAMBS BORN AT ABRO'S DRYDEN FIELD STATION 1976-1979

BREED	TOTAL NUMBER BORN (INCLUDES STILL BIRTHS)	PERCENTAGE NEO-NATAL DEATHS (<24 HRS) INCL. STILL BIRTHS	PERCENTAGE TOTAL PRE-WEANING DEATHS (4 MTHS) INCL. STILL BIRTHS	PERCENTAGE OF LAMBS UNFIT FOR EXPERIMENTATION EXCLUDES NEONATAL DEATHS
SCOTTISH BLACKFACE	307	4.2	11.1	1.9
BORDER LEICESTER	77	9.0	28.5	10.4
BORERAY BLACKFACE	35	0	2.9	0
CHEVIOT	105	9.5	14.3	4.8
FINNISH LANDRACE	165	10.9	20.0	9.1
TASMANIAN MERINO	104	9.6	23.0	9.6
OXFORD	50	2.0	6.0	0
SOAY	127	0	3.1	0.8
SOUTHDOWN	68	13.2	27.9	2.9
WELSH MOUNTAIN	181	3.3	6.6	1.1
TOTAL	1219	6.1	13.8	4.0

TABLE B CAUSES OF PRE-WEANING DEATHS IN LAMBS BORN AT DRYDEN 1976-1979

BREED	NO. OF PRE-WEANING DEATHS (4MTHS) INCL. STILL BIRTHS	ACCIDENT	STILLBIRTH AND PLACENTAL SMOTHERING	DISEASE	ABNORMAL LAMB	DIFFICULT LAMBING	STARVATION/ EXPOSURE	NUTRIT-IONAL DISORDER	CAUSE NOT ESTAB-LISHED
SCOTTISH BLACKFACE	34	5	7	7	3	2	5	3	2
BORDER LEICESTER	22	3	4	2	0	0	9	2	2
BORERAY BLACKFACE	1	0	0	1	0	0	0	0	0
CHEVIOT	15	0	6	2	1	2	2	0	2
FINNISH LANDRACE	33	3	7	2	4	1	9	5	2
TASMANIAN MERINO	24	1	6	3	1	3	8	1	1
OXFORD	3	0	0	2	0	1	0	0	0
SOAY	4	0	0	1	0	0	2	0	1
SOUTHDOWN	19	1	3	4	1	6	3	1	1
WELSH MOUNTAIN	12	2	4	1	1	0	2	0	1
TOTAL/ PERCENTAGE	167	9.5%	23.0%	15.0%	6.5%	9.0%	23.5%	6.5%	7.0%

TABLE C LAMB* TESTING AND SUBSEQUENT MORTALITY (1976-1979)

BREED	NO. OF LAMBS AVAILABLE TO TEST**	REJECTIONS FROM THOSE AVAILABLE TO TEST	NO. OF LAMBS TESTED	PERCENTAGE OF PRE-WEANING (4mth) DEATHS IN TESTED LAMBS	PERCENTAGE OF PRE-WEANING (4mth) DEATHS IN LAMBS NOT TESTED (EXCL. REJECTIONS)
Scottish Blackface	209	5	167	6.6	8.1
Border Leicester	46	8	29	24.1	11.0
Boreray Blackface	28	0	28	3.5	0
Cheviot	64	5	48	4.2	0
Finnish Landrace	95	15	39	5.1	12.2
Tasmanian Merino	45	10	28	21.4	57.1
Oxford	35	0	25	4.0	0
Soay	77	1	71	5.6	0
Southdown	42	2	27	14.8	7.7
Welsh Mountain	119	2	89	5.6	0
TOTAL	760	48	551	7.8%	8.7%

* Includes waterbathed and wind-tunneled lambs
**Excludes neonatal deaths

APPENDIX 2

Investigation of some of the factors involved in heat production during waterbath procedure, with consideration of methodological techniques

A careful attempt was made to follow the changes in heat production characteristics throughout immersion in the waterbath for two Scottish Blackface lambs.

METHOD. Prior to immersion the lamb was fitted with skin thermocouples at ear, foot, midside, head and axilla. All thermocouples were protected with waterproof tape. The lamb was placed in the waterbath as the main breed experiment, and base metabolic rate was estimated. Respiration rate, rectal and skin temperatures were recorded. The mask was then changed to one incorporating a recording pneumotachograph (on loan from Inveresk Research Musselburgh, Midlothian) monitoring the volume of pulmonary ventilation. Respiration rate and metabolic rate were allowed to restabilise at base levels, before tidal volume was measured. Special attention was paid to the level of respiration rate to guard against panting which would increase heat loss through respiratory evaporation. A dew point meter (on loan from the Scottish Institute of Agricultural Engineering, Penicuik, Midlothian) recorded wet and dry bulb temperature of inspired and expired air. The water in the bath was stirred continuously throughout all these estimations to ensure thorough mixing, so that water temperature could accurately influence skin temperature.

An earlier attempt to monitor the heart rate of lambs in the waterbath had proved unsuccessful as a result of poor sensitivity of

equipment regarding the separation of ECG trace from background noise of mixed amplitude caused through shivering. Various screening techniques were tried, but results were not convincing.

This procedure of alternate metabolic and tidal volume estimations was repeated three times in the TNZ before the water temperature drop was commenced. Once metabolic rate had increased and rectal temperature just started to fall (ie immediately pre-expected summit metabolism) water temperature fall was arrested and measurements repeated. Again three sets of measurements were taken. Once complete, water temperature fall was restarted and halted when rectal temperature fall rate increased, ie post summit metabolism, another set of metabolic and respiratory data were collected.

RESULTS. Metabolic rate, respiration parameters and air, skin and water temperatures are shown for each animal in Tables 47 and 48. Calculation of heat loss during respiratory exchange is given in Tables 47A and 48A. Results are available for three different stages of cooling in both cases. For lamb 104 measurements were made at base and pre- and post- summit metabolism. For lamb 105 base and pre summit measurements were taken at stages similar to 104 but the third set of measurements was made around summit metabolism. Results are recorded for each situation except in the case of lamb 105 where dew point and dry bulb temperature measurements for inspired and expired air were constant during each set of readings.

(i) Base Metabolism. During the period at base metabolic rate, rectal and skin temperatures, tidal volume, respiration rate and metabolic rate remained low and constant for both animals. Base

TABLE 47 PHYSIOLOGICAL RESPONSES, SKIN AND RECTAL TEMPERATURES FOR LAMB 104 IMMERSED IN A COOLING WATERBATH

MEASURE-MENT PERIOD	TIME OF MEASURE-MENT	META-BOLIC RATE KJ/MIN	RESPIR-ATION RATE BREATHS/ MIN	TIDAL VOLUME ML	MINUTE VOLUME L/MIN	RECTAL TEMP. °C	AIR TEMP. °C ABOVE HEAD	WATER TEMP. °C AVERAGE OF 2 READINGS	SKIN TEMPERATURES				
									HEAD	EAR	FOOT	MIDSIDE	AXILLA
BASE	10.45	1.0375	66	62	4.08	40	19.5	36.5	29.3	35.6	33.9	38.6	39.6
	10.47	1.1205	66	77	5.10	40	19.5	36.5	29.5	35.0	33.6	38.4	39.3
	10.51	1.0375	66	72	4.74	40	19.5	36.5	28.8	35.0	32.7	38.1	39.1
Mean		1.0651		70.3	4.62				29.2	35.2	33.4	38.4	39.3
±SE		±0.0277	66	±3.6	±2.46	±40	±19.5	±36.5	±0.21	±0.20	±0.36	±0.15	±0.15
PRE-	11.15	3.3615	74	254	18.78	40.3	17.6	25.9	31.5	26.5	24.5	29.3	27.9
SUMMIT	11.18	3.1955	66	216	14.28	40.2	17.6	25.8	32.8	26.0	24.7	29.3	29.1
META-	11.22	3.2785	64	252	16.4	39.8	17.8	25.5	29.5	26.5	23.9	29.2	28.7
BOLISM	11.25	3.5690	68	190	12.9	39.3	17.3	25.4	29.5	24.0	25.6	28.7	28.7
POST-	11.40	3.2508	80	94	7.65	37.2	15.6	20.6	27.4	20.5	21.8	24.5	22.5
SUMMIT	11.43	3.1609	72	88	6.36	36.3	15.4	20.6	26.9	20.5	22.0	23.8	23.0
META-	11.47	3.1609	56	86	4.8	35.3	15.1	20.6	27.9	20.0	21.1	24.5	24.7
BOLISM													

TABLE 48 PHYSIOLOGICAL RESPONSES, SKIN AND RECTAL TEMPERATURES FOR LAMB 105 IMMERSED IN A COOLING WATERBATH

MEASUREMENT PERIOD	TIME OF MEASUREMENT	METABOLIC RATE KJ/MIN	RESPIRATION RATE BREATHS/MIN	TIDAL VOLUME ML	MINUTE VOLUME L/MIN	RECTAL TEMP. °C	AIR TEMP. ABOVE HEAD °C	WATER TEMP. AVERAGE OF TWO READINGS °C	SKIN TEMPERATURES				
									HEAD	EAR	FOOT	MIDSIDE	AXILLA
BASE	12.48	1.2276	56	26	1.44	40.2	18.3	37.3	29.9	35.9	38.8	39.0	39.9
	12.55	1.1969	67	22	1.50	40.2	19.4	37.4	30.6	34.9	37.8	38.3	38.5
	12.58	0.9207	70	22	1.56	40.0	18.7	37.4	32.3	34.5	38.0	38.0	39.0
	Mean	1.1150											
	±SE	±0.0975											
PRE-SUMMIT METABOLISM	13-17	3.4372	80	68	5.46	39.5	17.4	28.5	28.8	21.8	29.1	31.0	32.5
	13.20	2.5166	82	54	4.44	39.5	18.3	28.3	29.3	20.8	28.8	31.0	32.5
	13.28	2.7621	82	61	4.98	39.5	17.4	28.7	28.1	18.6	28.6	31.5	32.0
AROUND SUMMIT METABOLISM	14.04	3.7442	72	23	1.68	38.3	17.1	19.2	28.1	18.2	19.6	24.5	27.4
	14.07	3.9897	86	24	2.04	37.9	17.6	19.1	32.0	18.4	19.1	22.3	23.8
	14.11	3.7135	72	33	2.4	37.4	17.6	19.1	31.3	18.6	19.1	22.8	25.7

TABLE 47A CALCULATION OF HEAT LOSS FROM RESPIRATORY TRACT OF LAMB 104 USING A PSYCHROMETRIC CHART (FIG. 12)

MEASUREMENT PERIOD	TIME OF MEASUREMENT	DEW POINT °C		DRY BULB TEMP. °C		C AIR FLOW RATE 1/MIN	A SPECIFIC ENTHALPY KJ/KG		B DENSITY KG M^{-3} (RECIPROCAL OF SPECIFIC VOL.)		A X B X C HEAT CONTENT J/MIN		1 - 2 / 1000 HEAT LOST FROM RESPIRATORY EXCHANGE KJ/MIN
		INSPIRED AIR	EXPIRED AIR	INSPIRED AIR	EXPIRED AIR		INSPIRED AIR	EXPIRED AIR	INSPIRED AIR	EXPIRED AIR	INSPIRED AIR 1	EXPIRED AIR 2	
BASE	10.45	9.75	15.0	18.8	19.1	15	38.0	46.5	1.196	1.186	681.82	827.40	0.1456
	10.47	10.0	15.0	19.0	19.5	15	39.0	47.0	1.195	1.841	699.08	834.81	0.1357
	10.51	10.0	15.25	18.8	19.8	15	38.25	47.50	1.195	1.183	685.89	843.20	0.1573
Mean ± SE													0.1462 ±.0062
PRE-SUMMIT	11.15	10.2	14.8	18.6	19.3	15	38.0	46.0	1.186	1.201	684.27	828.69	0.1444
	11.18	10.25	15.0	18.6	19.1	15	38.0	47.5	1.182	1.192	673.76	849.23	0.1755
	11.22	11.5	16.0	18.5	19.7	15	40.0	49.0	1.195	1.183	716.85	869.82	0.1530
	11.25	*	*	*	*	15							
POST SUMMIT	11.40	12.5	16.0	18.6	19.1	15	42.5	48.25	1.194	1.186	761.19	858.54	0.0974
	11.43	13.5	16.25	18.6	19.6	15	43.5	49.0	1.192	1.183	777.71	869.82	0.0921
	11.47	13.0	16.0	18.6	19.6	15	42.5	43.5	1.192	1.188	759.83	774.94	0.0151

* Dew point meter readings not stable

TABLE 48 A CALCULATION OF HEAT LOSS FROM RESPIRATORY TRACT OF LAMB 105 USING A PSYCHROMETRIC CHART (FIG. 12)

MEASURE-MENT PERIOD	TIME OF MEASURE-MENT	DEW POINT°C		DRY BULB TEMP°C		AIR FLOW RATE L/MIN C	A SPECIFIC ENTHALPY KJ/KG		B DENSITY KGM^{-3} (RECIPROCAL OF SPECIFIC VOL.)		A X B X C HEAT CONTENT J/MIN		1 - 2 / 1000 HEAT LOSS
		INSP-IRED AIR	EXPIR-ED AIR	INSP-IRED AIR	EXPIR-ED AIR		INSP-IRED AIR	EXPIR-ED AIR	INSP-IRED AIR	EXPIR-ED AIR	INSP-IRED AIR	EXPIR-ED AIR	FROM RESPIR-ATORY EXCHANGE
BASE	12.48					15							
	12.55	8.3*	12.0	18.0	19.0	15	35.25	41.5	1.200	1.1912	634.37	741.51	0.1071
	12.58					15							
PRE-SUMMIT META-BOLISM	13.7					15							
	13.20	9.9	16.5	17.8	18.2	15	37.0	48.0	1.199	1.1891	665.47	856.12	0.1907
	13.28					15							
AROUND SUMMIT META-BOLISM	14.04					15							
	14.07	7.5	15.6	17.4	18.3	15	32.5	46.5	1.2077	1.1898	588.77	829.86	0.2411
	14.11					15							

* only mean readings for each time group are shown as agreement within groups was very close.

metabolic rate was estimated at 12.4 and 15.9 ml02/Kgmin for lambs 104 and 105 respectively.

(ii) Pre-summit Metabolism.

Lamb 104 showed no real increase in respiration rate during this period, but tidal volume was increased 3.5 times over that at base level. Rectal temperature had just started to fall (1°C in twenty minutes): Head temperature increased slightly; other skin temperatures fell but were above water temperature. Ear and foot showed vasoconstriction. Metabolic rate increased 3.5 times over that of base, but at 38.7 ml02/Kgmin not to an expected PMR level.

Lamb 105:- Respiration rate increased slightly over base levels (20 percent). Tidal volume increased over base levels but less dramatically (2.5x) than for lamb 104. Rectal temperature had fallen 0.7°C from base levels but did not continue to fall through the period of measurement. All skin temperatures fell below base levels and ear and foot showed some evidence of vasoconstriction. Metabolic rate increased to 42.4ml02/Kgmin.

(iii) Around summit. (lamb 105 only). Respiration rate was similar to pre-summit levels for lamb 105, tidal volume returned to base levels. Rectal temperature fell steadily, 0.9°C in seven minutes. Head temperature increased slightly above pre-summit levels while other skin temperatures fell, ear and foot showing marked vasoconstriction.

(iv) Post-summit (104 only). Respiration rate was variable but not above previously recorded levels. Tidal volume fell towards base levels. Rectal temperature fall was rapid, 1.9°C in seven minutes. All skin temperatures had dropped towards water temperature. Metabolic rate was 37.6 ml02/Kgmin. A summit value of

48.07ml02/Kgmin had been recorded midway between times (ii) and (iv).

Metabolic rates in Tables 47 and 48 are recorded in heat production units (KJ) to allow ease of calculation of heat loss, using the thermal equivalent for oxygen as below:-

KJ = 20.46 102 (MacLean, 1972).

Thermal conductances (KJ /min ^{o}C) were estimated for both lambs at all stages.

$$\text{Thermal conductance} = \frac{MR}{Tr - Tw}$$

Where MR is metabolic rate KJ /min.

Tr = Rectal temperature*

Tw = Water temperature*

* these temperatures should be static at the time of estimation.

Thermal conductance fell from 0.304 to 0.201 KJ/min C for lamb 104 base to post-summit and from 0.398 to 0.212 KJ/min C for lamb 105 base to summit.

Heat loss from respiratory exchange was calculated using a psychrometric chart (see Fig 12, Tables 47A, 48A). Dry bulb and dew point temperatures were recorded for inspired and expired air using the dew point meter. From these two parameters, the specific enthalpy (heat content) and density of air sample can be read off the chart, density being the reciprocal of specific volume. The product of density and specific enthalpy computes an estimation of the heat content of the air sample. The difference between this estimate for

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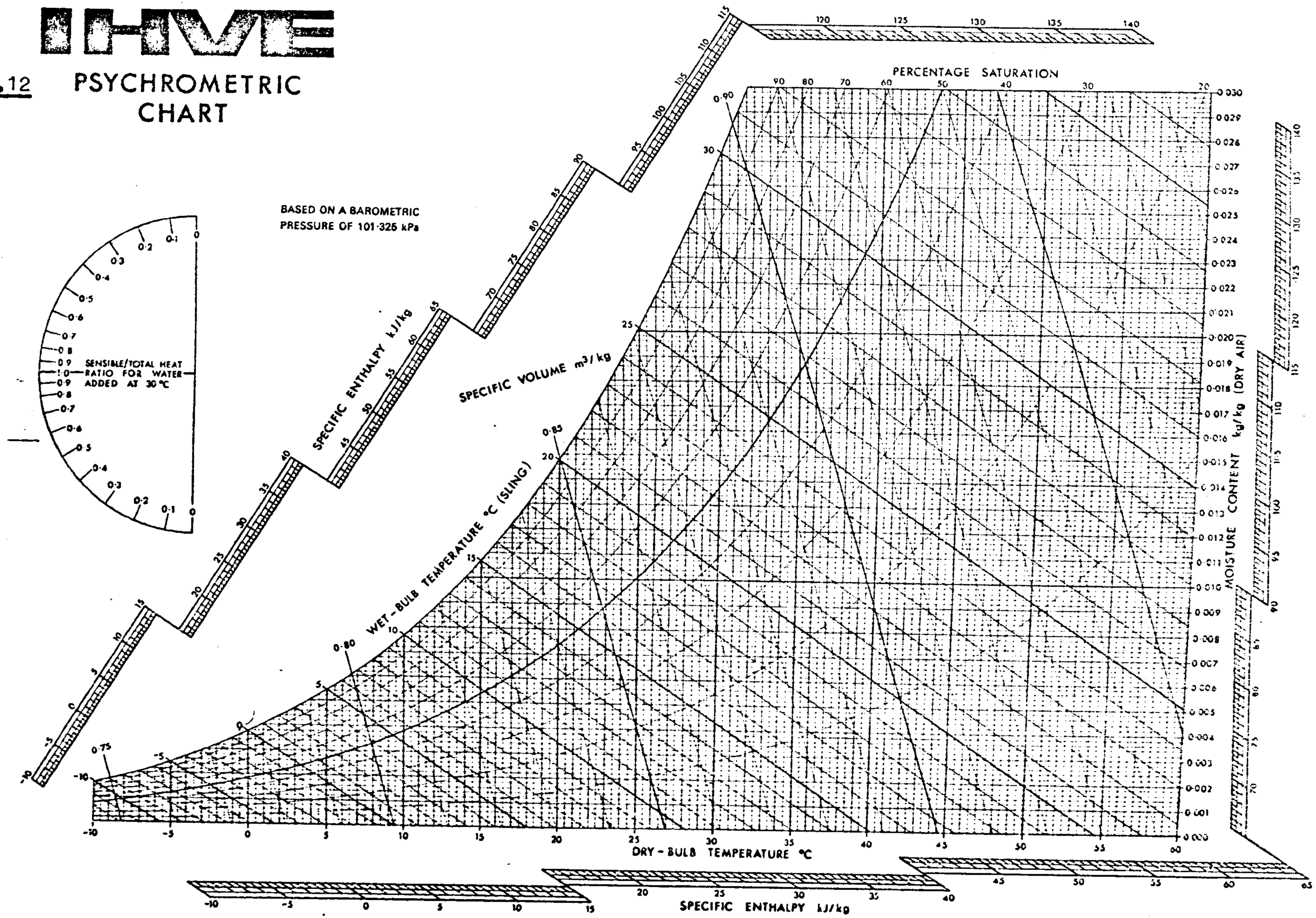
FIG. 12 PSYCHROMETRIC CHART



expired and inspired air gives the heat loss in respiratory exchange. For lamb 104 heat loss from this source fell from that equivalent to 14 percent of base metabolism to 4.8 and 2.8 percent of pre and post-summit metabolism levels respectively, equivalent estimates at base for lamb 105 was lower at 8.9 percent of base metabolic rate. This fell to 6.9 percent pre-summit and 6.4 percent at summit. Absolute value rose towards summit in both cases and declined post summit.

DISCUSSION. This carefully controlled experiment was designed to gain as much information into the methodological limitations of the waterbath technique, and to estimate the contribution of respiratory heat loss. In interpretation of the results it should be remembered that conclusions drawn may be open to question due to the small number of animals involved. Nevertheless several observations can be made.

The relationship of tidal volume and oxygen consumption was as expected, tidal volume increase being proportional to the rise in oxygen consumption. It is, however, noted in both animals that respiration rate is not linearly related to tidal volume. This suggests an insensitivity to carbon dioxide concentration of inspired air One explanation of this is that because of mask design (dead space), respiration rates are already, even at base, elevated by carbon dioxide levels. Possible evidence for this, in the absence of carbon dioxide measurements is seen in the dew point/moisture content measurements of the inspired air. Instead of remaining constant, the moisture content of the inspired air rose throughout the measurement period, implying that expired air may be contaminating the inspired

air due to build up in the mask and tube air supply system. If moisture can build up then it seems likely that carbon dioxide levels can surely rise as well. An alternative reason explaining the rise in moisture content of inspired air is that humidity in the immediate atmosphere will increase as water is piped from the waterbath during the cooling procedure. Evidence for elevated respiration rates at base is not convincing. Free breathing (non mask) respiration rates were not measured, but Mercer (1974) records respiration rates of 55 - 75 breaths per minute for lambs. Both lambs measured in this experiment lie in the mid-range. The haemodynamic changes resulting from immersion in water, ie increased venous return, pulmonary pooling and increased cardiac output, which in the human can result in a more than 30 percent increase (Arborelius, Balldin, Lilja and Lundgren, 1972) result in pulmonary oxygen extraction being increased so that smaller tidal volumes will be required to meet increased metabolic demands.

Thermal conductance drops as summit metabolism is approached. ie insulation rises towards summit metabolism as peripheral vasoconstriction rises to a maximum. After maximal vasoconstriction occurs (around the lower critical temperature), shivering produces increased metabolic rate resulting in an increased peripheral blood flow due to muscular action. Measurements of thermal conductance at periods when rectal and water temperatures are not steady are probably meaningless due to this muscular activity.

The rate of heat loss from the respiratory tract is dependent on the rate of moisture lost during the respiratory cycle which is dependent on respiration rate, tidal volume and the percentage saturation of inspired and expired air.

Respiratory heat loss for lambs at base levels is similar to that recorded for humans, 8 - 10 percent of base metabolic rate (Burton and Edholm, 1955). As metabolic rate increases heat loss is so high that the percentage respiration losses fall.

Thermal conductances at base metabolic rate estimation were also measured for two breeds used in the main waterbath experiment for breed comparison purposes. Data are reported in Tables 49 and 49A For 21 Scottish Blackface and 24 Soay lambs actually cold stressed in the main waterbath experiment. Significant breed differences were recorded for skin thickness ($p < 0.001$), and minimum metabolic rate ($p < 0.001$). No significant difference was found in rectal or water temperature prevalent during estimation. Significant differences were recorded between breeds for thermal conductance ($p < 0.02$). The regression of skin thickness on conductance is negative but non-significant. It should be remembered that the head represents 13 - 15 percent of total body area and was outside the cooling medium.

TABLE 49 THERMAL CONDUCTANCE AT MMR FOR 21 SCOTTISH BLACKFACE LAMBS IN A WATERBATH

LAMB IDENTITY	M.M.R. ($ML.O_2/KG.MIN.$)	RECTAL TEMPERATURE °C	WATER TEMPERATURE °C	SKIN THICKNESS (AVERAGE OF 5 SITES)(MM)	THERMAL CONDUCTANCE ($ML.O_2/KG.°C$)
1	15.7	39.2	37.0	3.9	7.14
2	12.4	39.2	36.0	5.4	3.88
4	13.9	39.2	36.2	4.3	4.63
5	12.6	38.7	37.0	4.1	7.41
10	11.0	38.8	37.4	4.1	7.86
14	18.6	39.5	36.5	4.1	6.20
17	13.1	39.0	37.0	3.5	6.55
18	11.7	39.0	37.9	3.6	10.64
28	15.4	38.9	37.5	4.3	11.00
29	12.3	39.0	37.5	3.9	8.20
30	10.5	39.5	37.0	4.1	4.20
36	15.0	37.9	36.6	4.1	11.54
37	16.1	39.4	36.5	3.8	5.55
38	18.5	39.2	36.2	4.6	6.17
39	10.8	39.5	37.2	4.2	4.70
46	12.1	38.8	36.2	4.8	4.65
47	20.7	40.1	36.5	5.0	5.75
48	14.6	39.9	37.0	4.4	5.03
82	13.9	39.6	37.2	4.7	5.79
83	20.3	40.0	37.0	3.7	6.77
85	12.8	39.4	36.5	5.1	4.41
Mean ±SE	14.38 ±0.66	39.23 ±0.109	36.85 ±0.06	4.3 ±0.11	6.57 ±0.49

TABLE 49 A THERMAL CONDUCTANCE AT MMR FOR 24 SOAY LAMBS IN A WATERBATH

LAMB IDENTITY	M.M.R. ($ML.O_2/KG.MIN.$)	RECTAL TEMPERATURE °C	WATER TEMPERATURE °C	SKIN THICKNESS (AVERAGE OF 5 SITES)(MM)	THERMAL CONDUCTANCE ($ML.O_2/KG.°C$)
2	16.9	38.7	36.5	3.1	7.68
3	15.7	39.2	36.4	2.9	5.61
4	19.2	39.4	36.2	2.7	6.0
6	25.0	39.3	36.5	3.8	8.93
7	23.4	39.1	36.1	3.3	7.80
8	25.9	40.1	36.3	3.4	6.82
9	18.2	38.8	37.0	2.7	10.11
10	22.5	39.4	36.2	2.3	7.03
13	28.6	39.0	37.0	3.0	14.3
14	19.7	39.4	36.8	3.2	7.58
15	19.8	39.4	36.5	3.7	6.83
16	20.3	38.8	36.2	3.0	7.88
17	18.2	39.0	36.3	3.0	6.74
18	33.3	40.0	36.5	3.1	9.51
19	17.8	39.6	38.0	3.1	11.13
22	22.9	40.1	39.0	2.8	20.82
25	15.0	39.1	38.0	3.2	13.64
26	15.0	39.8	37.0	2.1	5.36
27	16.2	39.8	37.2	3.6	6.23
34	26.8	39.1	37.5	2.9	16.75
35	20.5	39.5	37.5	3.1	10.25
36	21.3	39.7	36.5	2.9	6.66
37	13.2	38.9	36.5	3.1	5.50
41	14.2	39.0	37.0	3.1	7.10
Mean ± SE	20.41 ±1.01	39.34 ±0.086	36.86 ±0.15	3.1 ±0.06	9.01 ±0.79

GLOSSARY

ABRO	Animal Breeding Research Organisation.
ANOVA	Analysis of variance.
AMTE (PL)	Admiralty Marine Technology Establishment (Physiological Laboratories).
BAT	Brown adipose tissue.
BMR	Base metabolic rate.
CSIRO	Commonwealth Scientific and Industrial Research Organisation.
DVM	Digital Voltmeter.
EAAP	European Association of Animal Production.
HFRO	Hill Farming Research Organisation.
HMSO	Her Majesty's Stationery Office.
LCT	Lower critical temperature.
MLC	Meat and Livestock Commission.
MMR	Minimum metabolic rate.
NEFA	Non-esterified fatty acid.
NRPS	Naval Radiological Protection Service.
NSCA	North of Scotland College of Agriculture.
NST	Non-shivering thermogenesis.
PMR	Peak metabolic rate.
RQ	Respiratory quotient.
TNZ	Thermo neutral zone.
USDA	United States Department of Agriculture.

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DECLARATION

I declare that the work described in this thesis is entirely my own except where otherwise acknowledged.

(D.E. SAMSON)

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Hypothermia in newborn lambs induced by experimental immersion in a water bath and by natural exposure outdoors

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A progressively cooling water bath technique was developed to measure resistance to body cooling in newborn lambs. Cold resistance, defined as the time taken to reduce rectal temperature to 35°C, was measured in 429 lambs of 12 different breeds individually immersed in a water bath. Two alternative procedures were used with water temperature falling from 37°C to 12°C or from 25°C to 10°C. In lambs tested twice the repeatability of cold resistance was high: 0·95 and 0·81 respectively in the two types of test. There were clear breed differences in cold resistance, some breeds being up to three times more resistant than others. Health was unimpaired by treatment and preweaning mortality was not affected. Ten of the breeds represented in water bath tests were also used for measurements of rectal temperature 1 h after birth in the field. There was some similarity in the breed rank order for ability to resist hypothermia in the field and in the water bath. Water bath tests of hypothermia in lambs could facilitate genetic selection for improved perinatal survival in the field.

MORTALITY AMONG NEWBORN lambs has been estimated at about 350,000 per year on Scottish hill farms (Thomson and Aitken 1959) and between one and a half and four million in Britain as a whole (Wiener *et al* 1973). Preweaning mortality may vary from about 15 to 20 per cent on typical Argyll hill farms (Houston and Maddox 1974) and up to 45 per cent in special circumstances (R. G. Gunn, personal communication; Wilson 1954). True overall mortality rates may be higher since accurate survey data are likely to come from the best managed farms. Cold stress and undernutrition are interacting causes of perinatal death (Slee 1977a) and together they could account for about 50 per cent of total mortality other than stillbirths (Slee 1976).

Many dead lambs classed as 'starved' may have died because hypothermia caused immobility and prevented suckling. Other lambs, apparently stillborn, may have died from acute hypothermia very quickly after birth. Cold exposure involving less serious hypothermia can inhibit the sucking drive (Alexander and Williams 1966) and reduce the rate of energy replenishment when demand is greatest.

If cold resistance is an important aspect of lamb survival and if there is a genetic component, it may be useful to develop a simple standard test for cold resistance as an aid to artificial selection. The procedure must discriminate between lambs of widely different cold resistance without the exposures being too short (giving poor discrimination), too long (experimentally inconvenient) or imposing too high a chill index (Siple 1964) which could cause superficial tissue damage. Some of these constraints applied to previous work (Slee 1978).

The purpose of the present paper is to evaluate some laboratory tests of cold resistance. A suitable test should distinguish differences between breeds relating to their viability as newborn lambs in the field without prejudicing the subsequent recovery and health of the lambs. The paper describes the development and use of different procedures involving the immersion of one- to three-day-old lambs in a water bath. Two methods gave repeatable measurements of cold resistance and were capable of distinguishing differences between breeds. Resistance to hypothermia was also measured in newborn lambs exposed to cold weather in the field. Breed performances could therefore be compared crudely under field and laboratory conditions.

Materials and methods

Water bath tests

Between 1976 and 1979, 429 lambs aged from 0·5 to 62 h were subjected to body cooling by standard forms of immersion in a water bath. In addition, 122 lambs were used for preliminary tests and for other procedures involving induced hypothermia. These lambs are included in the mortality data (Tables 3 and 4) but not in Tables 1, 2 and 5. Thirty-nine lambs were treated twice on successive days to obtain estimates of repeatability of resistance to cooling. The lambs were drawn from the following breeds:

Scottish Blackface, Soay, Finnish Landrace, Cheviot, Welsh Mountain, Border Leicester, Boreray (St Kilda) Blackface, Tasmanian Merino, Oxford Down, Southdown and ABRO (Animal Breeding Research Organisation) damline synthetic (Smith *et al* 1979). In addition, 29 New Zealand Romney × Scottish Blackface and 34 Romney × ABRO damline lambs were used. The Romney rams carried genes for conferring long birthcoats on their lambs (Dry 1955; Wickham and Rae 1977). These breeds gave a wide range of litter size, birth weight, conformation and birthcoat type for evaluating different cooling procedures. The flocks had been maintained for several years at the ABRO field station where the experiments were carried out, except for the ABRO damline and Romney cross breeds and some Finnish Landrace and Merinos which were brought from ABRO farms four weeks before lambing.

All the lambs had been suckled naturally before removal from the mother. They were weighed before immersion. Two water baths, measuring $68 \times 53 \times 53$ cm and $61 \times 76 \times 30$ cm respectively, were used. The lambs were totally immersed except for the head. Water bath temperature and lamb rectal temperatures were measured by copper-constantan thermocouples connected to a recorder scanning at 1 or 5 min intervals. The rectal thermocouple was inserted 6 cm. Water temperature was taken as the average temperature recorded by two thermocouples 15 cm below the water surface. Trials indicated a maximum vertical temperature gradient of 2°C in the water bath. This gradient became less at low water bath temperatures and was reduced by movement of the lamb.

The initial water temperature was usually 25°C or 37°C, but occasionally lower starting temperatures of 20°C or 15°C were used. Water temperature was lowered by the addition of a constant flow of cold water. Preliminary simple methods of cooling were tried on a few lambs. For example, 23 lambs were immersed at fixed water temperatures between 15°C and 25°C for varying lengths of time until they became hypothermic. These trials failed to define a single water bath temperature suitable for all lambs and suggested that the best discrimination would be achieved by a fairly slow progressively falling water temperature. Consequently one of two cooling procedures was used for the remaining lambs. In the first the lambs were kept for 15 min at 25°C, then cooled to reach 20°C after a further 30 min, 15°C after a further 30 min and 10°C after a total of 2 h. In the second test lambs were held for 15 to 20 min at approximately 37°C (or whatever temperature was found to be thermoneutral for each lamb being tested), then cooled to reach 24°C after a further 30 min, 20°C after a further 30 min, 15°C after a further 60 min and 12°C after a total of 2·5 h. The period of immersion was determined by the resistance to hypothermia of each individual lamb. Cooling continued until rectal temperatures reached either 36°C or 35°C. The time taken for this was used as a measure of cold resistance. The cooling curves of lambs which were cooled only to 36°C were extrapolated to obtain cold resistance times equivalent to those cooled to 35°C. All computations were carried out using 35°C cooling times or the equivalent.

The degree of hypothermia induced was intended to define the point at which lambs became unable to thermoregulate, while minimising discomfort. Preliminary trials showed that rectal temperatures could be reduced from 39°C to 35°C without apparent discomfort. Some lambs stabilised their temperatures between 36 and 37°C, so it was necessary to induce temperatures below 36°C to establish the point of failure of thermoregulation. Sykes *et al* (1976) and Slee (unpublished) found that rectal temperatures between 25 and 30°C occurred in newborn lambs outdoors in severe weather. After artificial rewarming indoors, this was tolerated without deleterious after-effects. Artificially induced hypothermia down to 35°C was therefore likely to be harmless.

On removal from the water bath the lambs were swabbed with cotton wool for 1 min, transferred to a room maintained at 28°C and placed in a wire cage (floor diameter 45 cm) under a 2·5 kw fan heater. The lambs remained in this environment for a minimum of 25 min. Rectal temperatures were monitored until they reached 38°C. The lambs were then returned to their mothers which were kept in individual pens or adoption crates.

Field observations

Rectal temperatures of 249 lambs were measured in the field 1 h after birth. A portable electric thermometer (Light Instruments) with a thermistor probe inserted 6 cm into the rectum was used. Ten of the breeds involved were the same as those used in the water bath experiments so that between-breed comparisons between resistance to hypothermia in a water bath and in outdoor conditions were possible. The lambs were born outdoors in a variety of weather conditions. Weather severity was assessed by measurements of ambient temperature in the shade and wind speed at lamb height.

Results

Preliminary trials

Two Blackface lambs immersed at 25°C showed no change in rectal temperature after 75 min whereas

two Finnish Landrace lambs became hypothermic (rectal temperature below 36°C) after 15 min at the same water temperature. When two Cheviots and five Soays were immersed at 20°C, all the Soays became hypothermic after between 8 and 45 min, whereas the Cheviots did not become hypothermic until after 80 to 110 min. In two Welsh Mountain lambs and three Blackfaces immersed at 20°C and progressively cooled to a water temperature of 10°C hypothermia ensued after 70 to 110 min. Nine lambs immersed at 15°C varied in becoming hypothermic, taking between 8 min and 60 min with only a small change in rectal temperature. Apparently in some lambs hypothermia was slow to occur even at water temperatures of 20°C and below. In other lambs uncontrolled hypothermia occurred quickly even at water temperatures above 20°C, so some thermoregulatory responses would be difficult to monitor. A single constant water temperature was thus unsuitable for testing all lambs. Progressive cooling procedures were adopted for the remaining trials.

Water bath test 1*: cooling from* 25°C

One-hundred-and-sixty-three lambs were tested. Eleven became hypothermic within 15 min, before the water temperature was lowered; the remainder were subjected to the standard cooling procedure until their rectal temperatures reached either 36°C or 35°C. The procedure was well tolerated by most lambs. Brief struggling for periods of about 10 sec, occurring perhaps three or four times during immersion, occurred in about half the lambs but did not significantly affect rectal temperature.

Cold resistance. The overall average cold resistance for all lambs involved in test 1 was 66 min. Breed means, unadjusted for the possible effects of birth weight, birthcoat type, litter size, age, etc (Slee 1978), are shown in Table 1. The breed differences were large and significant overall ($P < 0{\cdot}001$).

TABLE 1: Resistance to body cooling expressed as the number of minutes of water bath immersion required to reduce rectal temperature to 35 °C (test 1)

	Number of lambs	Mean birth wt (kg)	Mean cold resistance (min)
Boreray Blackface	6	3·0	87
Border Leicester	10	5·3	81
Romney crosses	63	4·1	78
Scottish Blackface	38	4·1	75
Soay	28	2·1	38
ABRO	6	3·8	35
Finnish Landrace	12	2·7	21

Water bath test 2*: cooling from* 37°C

Two-hundred-and-sixty-six lambs were tested. The initial water temperature was varied between 36°C and 39°C, the precise temperature being that at which metabolic rate (Samson and Slee, unpublished) was minimal for each lamb. Generally small lambs required higher water temperatures. At thermoneutrality some lambs were completely relaxed. Struggling occurred for brief periods only and to a similar extent in each breed. Rectal temperatures were not apparently affected by behaviour. All rectal temperatures were taken down to 35°C in these tests.

Cold resistance. The overall average cold resistance for the 10 breeds involved in test 2 was 61 min. The unadjusted breed mean values are shown in Table 5 (column 5). As in test 1, the breed differences were significant ($P < 0{\cdot}001$). Five breeds were represented in both series of water bath tests. Of these the Scottish Blackfaces, Border Leicesters and Soays showed similar mean cold resistance in both tests. However the Finnish Landraces showed significantly ($P < 0{\cdot}001$) better and the Boreray Blackfaces significantly ($P < 0{\cdot}05$) poorer resistance in test 2 compared with other lambs of the same breed in test 1.

Repeatability

Thirty-nine lambs (involving 10 different breeds) were tested twice on successive days, using the same procedure. The correlations of repeatability of cold resistance were highly significant ($P < 0{\cdot}001$) for both types of test (Table 2).

TABLE 2: Repeatability of resistance to body cooling during water immersion on two successive days

	Type of immersion	
	Test 1 Cooling from 25 °C	Test 2 Cooling from 37 °C
Number of lambs	21	18
Mean resistance to cooling (min)		
1st immersion	65	53
2nd immersion	69	56
Mean time between immersions (h)	22	21
Correlations between 1st and 2nd immersion times	0·81	0·95

Recovery, remothering, health and mortality

After lambs were removed from the water bath their rectal temperatures continued to fall for about 5 min before recovery began. The average minimum

temperature recorded was 33·8°C for all lambs. Some lambs, particularly Finnish Landraces and Merinos, were weak immediately after immersion but recovered full mobility within about 10 min as their body temperatures rose above 36°C.

The average time required for rectal temperature to return to 38°C during rewarming was 22·9 min for all lambs. This time differed significantly between breeds ($P < 0·01$) with the Boreray Blackfaces and Soays recovering fastest and the Oxfords, Border Leicesters and Southdowns slowest.

After recovery some lambs were rejected by their mothers. In 1976 there were few such cases but in 1977 serious difficulty was experienced with about 10 per cent of the lambs treated. The most successful counter-measures were rubbing the lamb with the placenta and penning the ewe in an adoption crate. In 1978 all ewes were penned from the time the lambs were removed until about 30 min after the lambs returned. Rejection was rare with this procedure.

Generally there were no health problems following water bath treatments. Four lambs died within a few days of treatment, one of these with pneumonia and one showing a 'watery mouth' condition. However similar deaths were recorded among untreated contemporaries.

Apart from stillbirths and perinatal deaths, lambs could be classified into three main categories: lambs given water bath tests, lambs rejected for test because of unfitness and lambs untested for other reasons. Grounds for rejection included: unthriftiness, overt illness or deformity and maternal deficiencies such as a shortage of milk. Table 3 shows

TABLE 3: Mortality rates among lambs tested for cold resistance, untested lambs and lambs rejected as unfit for test

Lamb classification	Number	% of total
Available for test*	760	100
Tested	551	72·5
Not tested	161	21·2
Rejected unfit	48	6·3
Pre-weaning mortality		
Tested lambs	43	7·8
Untested lambs	14	8·7
Rejected lambs	13	26·5

* Excluding neonatal deaths, lambs born in 1976 (not classified), ABRO damlines, Romney crosses and lambs allocated to other experiments

the average mortality rates in these classes and indicates that water bath treatment had no significant effect on subsequent viability recorded up to weaning at four months old. Lambs which were rejected subsequently had a significantly ($P < 0·001$) higher mortality rate than all other lambs. In Table 4 these classes of lambs are pooled to show overall mortality rates in the different breeds. There were large and significant ($P < 0·001$) differences between breeds; the two feral breeds and then the hill breeds, with the Oxford Downs, having generally the lowest mortality.

TABLE 4: Mortality rates among lambs of 10 pure breeds born on the same station 1976–1979

	Number born	Percentage perinatal deaths including stillbirths	Percentage pre-weaning deaths including stillbirths
Boreray Blackface	35	0	2·9
Soay	127	0	3·1
Welsh	181	3·3	6·6
Scottish Blackface	307	4·2	11·1
Cheviot	105	9·5	14·3
Oxford	50	2·0	6·0
Finnish Landrace	165	10·9	20·0
Merino	104	9·6	23·1
Southdown	68	13·2	27·9
Border Leicester	77	9·0	28·5
Total	1219	6·1	13·8

Mortality figures include all tested and untested lambs, and those rejected as unfit for test. Perinatal deaths include only lambs dying within 24 h of birth

The relationship between field mortality and water bath cold resistance in the different breeds was not precise, but three breeds—Finnish Landrace, Southdown and Merino—had consistently low cold resistance and high mortality.

Hypothermia in the field

Table 5 shows rectal temperatures of lambs in the field 1 h after birth. Low temperatures indicate a partial failure to thermoregulate. Weather conditions were variable but similar on average for each breed except the Soays which encountered higher temperatures at lambing. Mean effective ambient temperature—allowing a decrement for wind (Slee 1977b)—was +4°C for the Soays and between +1°C and −2°C for the other breeds. The variation between breeds in rectal temperature was highly significant ($P < 0·001$), confirming the evidence of Sykes *et al* (1976) that breeds differed in resistance to hypothermia in the field soon after birth.

On the basis of field measurements a proportion of lambs of each breed was classified as hypothermic. This class (comprising 20 per cent of all lambs) included all those with rectal temperatures below 37·5°C 1 h after birth (Table 5). Observations

TABLE 5: Relationship between natural hypothermia in the field and resistance to induced hypothermia in a water bath (test 2)

Breed	Field measurements			Water bath cold resistance	
	n	Mean rectal temperature (°C) 1 h after birth	Percentage of lambs hypothermic (rectal temperatures below 37·5 °C)	n	Mean number of min immersion required to reduce rectal temperature to 35 °C
Cheviot	22	39·6	9·1	35	98
Scottish Blackface	64	39·6	1·6	33	87
Boreray Blackface	9	39·5	0	25	55
Welsh	47	39·3	8·5	21	89
Oxford	12	39·2	0	21	79
Soay	27	39·2	14·8	38	36
Southdown	17	37·6	47·1	26	51
Border Leicester	17	37·4	36·4	23	80
Merino	16	34·7	68·8	21	45
Finnish Landrace	13	32·8	84·6	23	38

suggested that lambs became less active as their temperatures fell below 37°C.

The 10 breeds observed outdoors were also represented in the second series of water bath tests and the mean resistance to cooling for each breed, based on these tests, is shown in Table 5. The breeds with high (ie, normal) rectal temperatures in the field—particularly the three hill breeds—tended to perform well in the water bath test. Three other breeds (Finnish Landrace, Merino and Southdown) ranked low on each criterion. The Soays and Border Leicesters varied in performance between the two tests.

Discussion

These results demonstrate a reliable method for measuring the resistance to hypothermia of newborn lambs using a controlled temperature water bath. The test allowed a wide range of response between animals with a high repeatability within animals. The required degree of induced hypothermia was less than that encountered among newborn lambs in the field (Sykes *et al* 1976; Slee, unpublished). Moreover, the technique is simple enough to be used outside the laboratory, for example, on an experimental farm. The procedure is precisely controllable since the cooling medium is in close and uniform contact with the whole surface of the animal, irrespective of posture, and its temperature can be accurately controlled. The high specific heat of water permits rapid cooling without a large temperature gradient and without excessive discomfort or risk of frostbite. Lambs of many different breeds, varying in size, coat type and environmental niche, were capable of withstanding hypothermia induced by water bath treatment without undue discomfort or subsequent ill effects. The test was capable of distinguishing breed differences in cold resistance. However no single cooling procedure was ideal for lambs of widely different cold resistance. Relatively cold water produced very fast rates of fall of body temperature in lambs of low cold resistance. This gave poor discrimination and prevented other physiological data (for example, basal or summit metabolism) from being obtained. Warmer water required unacceptably long immersions for cold resistant lambs. The problem was minimised by the use of progressive cooling rather than immersion at a fixed temperature. Finnish Landrace and Boreray Blackface lambs differed in cold resistance according to the type of cooling used. In some cold resistant lambs, slow cooling procedures may not excite the cold receptors sufficiently to elicit the maximum metabolic response. This can occur in man if there is only a small temperature gradient between the skin and the cooling medium (Burton and Edholm 1955). Such lambs might be stimulated more readily to maximum heat production by a fast cooling procedure producing a sharp stimulus. In other lambs heat loss may be too fast for heat production to maximise before metabolic rate is limited by the fall in body temperature. The cooling procedure which elicits the maximum metabolic response might be different for different lambs and different breeds.

A limitation of the water bath test, if it is to be used to select lambs for resistance to cold, lies in its difference from the type of stress experienced by lambs in the field. For this reason other tests of cold resistance involving low temperatures, wind and/or artificial rain are being evaluated in this laboratory. One previous experiment using wind (4 mph) and cold (down to −20°C) in climate chambers showed breed differences in cold resistance between Blackface, Welsh Mountain and Merino lambs (Slee 1978). The range of cold resistance was very wide (Blackfaces were four times more resistant than Merinos) perhaps because this test was more sensitive than the water bath test to differences in birthcoat

insulation. However dry cold and wind produce only slow rates of body cooling and so the climate chamber tests were unsuitable for large numbers of cold resistant lambs.

A water bath test would probably be suitable for genetic selection towards greater cold resistance in newborn lambs. Progress would depend upon the existence of genetic variation and a sufficiently high heritability. The breed differences found here and the high repeatability within lambs suggest that these requirements may be met. The usefulness of such selection in an agricultural context depends upon the physiological similarity between water bath cold resistance and resistance to cold stress in the field and upon the importance of hypothermia as a cause of natural mortality in the field. The high ranking of the three commercial hill breeds (Cheviot, Welsh Mountain, Scottish Blackface) for water bath cold resistance suggests that the test may be relevant. Moreover the cross comparisons obtained between the same breeds studied in the field (rectal temperature 1 h after birth) and in the water bath showed fairly good agreement. The breeds showing the greatest difference in performance between the field and water bath environments were the Soays (better in the field) and the Border Leicester (worse in the field). Immediately after birth Soays are fast and Border Leicesters slow to rise and suck. Such behavioural differences may indicate differences in the rate of physiological maturation (including thermoregulation) after birth. If breeds such as the Border Leicester were physiologically immature at birth this might explain their relatively better performance in the water bath about 20 h after birth than in the field 1 h after birth. The reverse would apply to the Soay.

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FACTORS AFFECTING RESISTANCE TO INDUCED BODY COOLING IN NEWBORN LAMBS OF 10 BREEDS

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ABSTRACT

1. The ability to resist hypothermia was measured in 265 lambs of 10 breeds immersed in a progressively cooling water bath.

2. Cold resistance varied significantly between breeds, with hill lambs showing the highest resistance. Hill breeds and feral breeds together had the highest weight-specific cold resistance.

3. Cold resistance was positively correlated with birth weight and skinfold thickness.

4. Age at test varying from 1 to 60 h did not significantly affect cold resistance.

5. Rate of recovery from hypothermia varied slightly between breeds. The feral lambs tended to recover fastest.

INTRODUCTION

VARIATIONS in winter weather can grossly affect the mortality rates of adult sheep and lambs (Blaxter, 1964). Several surveys, e.g. Houston and Maddox (1974), and Speedy, Linklater, Mackenzie, Macmillan and Blance (1977), suggest that 30 to 50% of perinatal deaths may be attributed to cold and cold-induced starvation. Short-term fluctuations in weather from warm conditions to conditions of cold, wind and rain can also produce large differences in perinatal lamb mortality rates, e.g. from 15% to 91% in Merinos (Obst and Day, 1968) and from 7% to 42% in Welsh lambs with fine birthcoats (Purser, 1967). Such variable effects of weather must reduce the uniformity of impact, and therefore the efficiency, of natural selection in improving genetic resistance to cold. Considerable genetic variation in cold resistance might therefore be available even in hill sheep. However, at present, little is being done to improve the hardiness of hill sheep by genetic means. Traditional methods of selecting rams for breeding may be irrelevant or even deleterious with respect to hardiness, and there is little scope for selection on the female side in hill flocks where most females have to be retained.

To be suitable for selection purposes, a cold resistance test should be controllable, repeatable, economic and simple, to allow easy application to a large number of animals. A test employing dry cold and wind was used by Slee (1978), but was not suitable for use on a large scale.

However, immersion of young lambs in a progressively cooling waterbath was later used successfully to test ability to resist hypothermia (Slee, Griffiths and Samson, 1980). Some of the procedures gave highly repeatable results and the subsequent health and viability of the lambs was unimpaired. Crude comparisons suggested that breed differences in waterbath cold resistance were fairly closely paralleled by the ability of the same breeds to resist hypothermia shortly after birth in the field.

In this paper, using a standard waterbath test developed by Slee *et al.*, (1980), we evaluate some of the characteristics of the newborn lamb in relation to its cold resistance: for example, breed, birth weight, birthcoat characteristics, age and skinfold thickness.

MATERIAL AND METHODS

Two hundred and sixty-five lambs of 10 different breeds were used. The lambs were born (some indoors and some outdoors) at the Animal Breeding Research Organisation Field Laboratory, Roslin, Midlothian between 1976 and 1979. Details of the experimental method were described by Slee *et al.* (1980). Some of those data are included in the present analysis but other lambs were omitted or replaced to ensure that each breed was comparable with respect to management, nutrition, place of origin,

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TABLE 2

Resistance to body cooling computed from the number of minutes of immersion required to reduce the body temperature of lambs to 35°C in a progressively cooling waterbath†

	1		2		3		4		5	
Breed	Raw unadjusted cold resistance (min)		Temperature transformed cold resistance		Cold resistance adjusted for other effects†		Cold resistance adjusted for other effects and birth weight†		Cold resistance adjusted for all significant effects†	
	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.	Mean	s.e.
Cheviot	98	4·3	34·8	3·7	27·4	5·3	22·8	4·3	17·7	4·9
Welsh Mountain	89	4·6	30·1	4·1	26·4	5·3	24·5	4·7	16·8	5·0
Scottish Blackface	87	4·4	25·3	2·7	30·8	7·0	29·9	6·5	23·3	6·1
Oxford Down	81	5·7	24·1	3·4	40·0	13·0	23·3	8·0	22·5	8·7
Border Leicester	80	5·3	23·0	3·0	22·1	5·3	14·7	3·7	14·4	3·9
Boreray Blackface	55	5·1	11·3	1·4	5·0	2·2	8·6	3·8	9·3	4·3
Southdown	51	3·9	10·4	1·3	7·9	1·7	6·5	1·4	6·1	1·9
Tasmanian Merino	45	5·6	8·0	1·1	5·3	1·2	5·5	1·2	8·4	2·6
Finnish Landrace	38	5·3	5·8	0·8	7·6	2·1	7·6	2·0	6·7	3·4
Soay	36	4·1	5·3	0·5	3·6	0·8	6·3	1·6	6·9	2·2

†Apart from the raw data in column 1 the terms fitted in the model were as follows: column 2, breed only; column 3, breed, date of test, sex, age (standardized at 13 h) and initial rectal temperature; column 4, breed, date of test, sex, age and $\log_{10}$ weight (standardized at the Blackface mean values) and initial rectal temperature; and column 5, all terms with significant ($P<0·1$) effects as indicated in Table 3.

$\log_{10}$ temperature transformed cold resistance was used for the analysis. The transformed cold resistance times in columns 2–5 may be multiplied by 23 to represent cold exposure in degree minutes (see MATERIAL AND METHODS).

TABLE 3

Least squares analysis, significance levels, mean squares and F ratios for all variables affecting cold resistance

Variable	d.f.	Mean square	F ratio	Significance level
Breed	9	0·1779	4·65	***
Date of test	137	0·0746	1·95	***
Litter size	2	0·1213	3·17	*
Sex	1	0·1453	3·80	$P<0·1$
Skin thickness	1	0·3956	10·34	**
Weight	1	0·2178	5·69	$P<0·02$
Age	1	0·0984	2·57	$P<0·1$
Initial rectal temperature	1	0·2655	6·94	**
Remainder	111	0·0383		

temperature on cold resistance, although significant, was small ($r = +0{\cdot}24$, $P < 0{\cdot}02$).

The significance of all effects is shown in Table 3. The breed differences in unadjusted cold resistance were highly significant ($P < 0{\cdot}001$), with the hill breeds proving most resistant. These differences were partly due to between-breed variation in birth weight and skin thickness, which also significantly affected cold resistance. However, after the effects of skin thickness and birth weight were adjusted for by least squares analysis, the breed differences were still highly significant ($P < 0{\cdot}001$).

The approximately linear between-breed relationship between cold resistance and birthweight is shown in Figure 2. Lambs of the

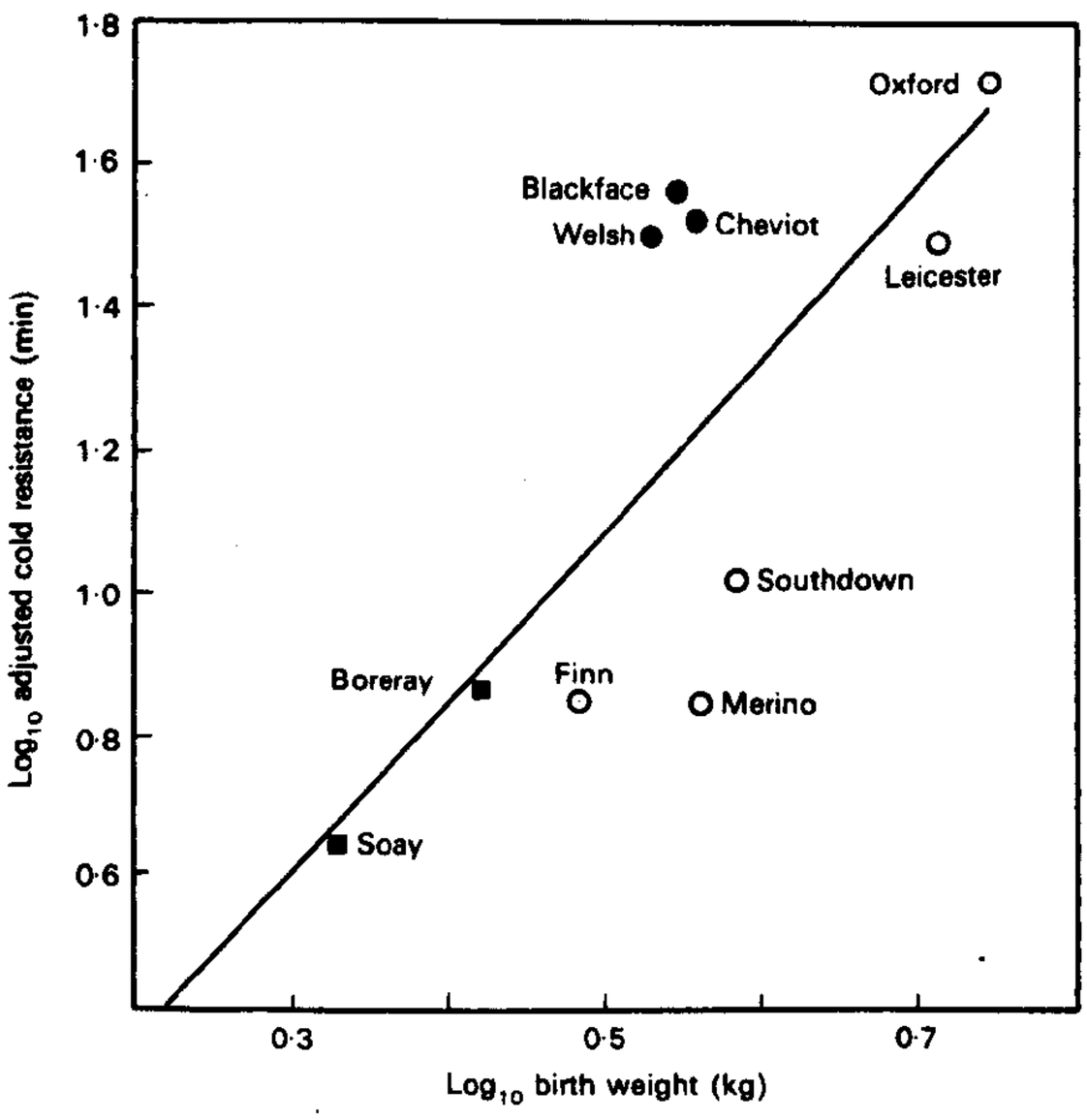

FIG. 2. The relationship (using the best linear fit) between $\log_{10}$ birth weight and $\log_{10}$ transformed cold resistance adjusted for the effects of sex, age, litter size and date of test. Separate symbols are used for the lowland breeds (○), hill breeds (●) and feral breeds (■).

hill breeds (Blackface, Welsh, Cheviot) showed a relatively high level of weight-specific cold resistance. Within breeds the relationships between cold resistance and either skin thickness or birth weight were generally positive and approximately linear. These two variables were also correlated with each other ($r = +0{\cdot}62$, $P < 0{\cdot}001$). When both were fitted in the model the significance of each separate effect was therefore reduced.

Cold resistance was not significantly affected by sex, age at test, or litter size. The time (date) of test did influence cold resistance but the cause of this effect was unknown.

The effect of the birthcoat on cold resistance was assessed from measurements of coat depth on all lambs (Table 1), and from data on wool sample weight per unit area of skin in a separate group of Blackface and Cheviot lambs (Table 4).

TABLE 4

Mean birthcoat weight per unit area of skin and mean resistance to body cooling

Breed	Cheviot		Blackface	
No. of lambs	19		45	
	Mean	s.e.	Mean	s.e.
Wool sample weight ($\mu g/mm^2$ skin area)	310	20	430	15
Cold resistance (min)	104	6·7	67	3·6
Correlation between cold resistance and wool sample weight	+0·55		+0·53	
Level of significance	$P < 0{\cdot}02$		***	

Across all lambs in the main experiment coat depth varied significantly between breeds (Table 1) but did not affect cold resistance. In the additional lambs mean wool sample weight was significantly greater in the Blackfaces ($P < 0{\cdot}001$) but cold resistance was significantly greater in the Cheviots ($P < 0{\cdot}001$). However, within both breeds, cold resistance was positively correlated with wool sample weight (Table 4). Also, wool sample weight was positively correlated with birthcoat depth ($r = +0{\cdot}64$, $P < 0{\cdot}001$) despite the fact that only the former significantly affected cold resistance.

3. *Rate of fall of rectal temperature*

The rate of fall of body temperature as it approached 35°C during the final 10 min of the test (terminal fall) represented the rate of approach towards severe hypothermia and, therefore, the extent to which thermoregulation was impaired. Breeds were significantly different in the terminal rate of fall of rectal temperature (Table 5) and therefore in the shape of cooling curve. In general, the most cold resistant breeds (Cheviot, Welsh, Blackface) showed flatter cooling curves with a delayed onset of

TABLE 5

Terminal fall of rectal temperature to 35°C during final 10 min of immersion and recovery time required for rectal temperature to return to 38°C after immersion

Breed	Terminal fall rate (°C/min) Mean	s.e.	Recovery time (min) Mean	s.e.
Cheviot	0·092	0·010	23	1·1
Welsh	0·136	0·013	24	1·4
Scottish Blackface	0·132	0·010	24	1·1
Oxford	0·098	0·013	26	1·4
Border Leicester	0·117	0·012	26	1·3
Boreray Blackface	0·176	0·012	20	1·3
Southdown	0·211	0·012	23	1·2
Merino	0·198	0·013	25	1·4
Finnish Landrace	0·213	0·012	26	1·3
Soay	0·213	0·010	23	1·0
Significance of breed variation	***		*	

hypothermia and a slower rate of progression into hypothermia. The terminal fall was negatively correlated with cold resistance ($r = -0{\cdot}68$, $P < 0{\cdot}001$), birth weight ($P < 0{\cdot}05$) and age ($P < 0{\cdot}05$). After adjustment for these effects the variation between breeds was reduced, but still significant.

4. Recovery from hypothermia

Unadjusted breed differences in rate of recovery after test were fairly small but just significant (Table 5), with the Boreray Blackfaces recovering fastest. Recovery rate was also influenced by sex ($P < 0{\cdot}05$), and slightly but not significantly affected by litter size and age. The sex effect was such that female lambs recovered, on average, 2 min sooner than males. Least squares breed means did not differ significantly. There was no correlation between rate of recovery and the previously determined cold resistance, and terminal fall of rectal temperature at the end of test, either within or across breeds.

DISCUSSION

The results indicate significant breed differences in the ability of newborn lambs to resist hypothermia during a standard cooling procedure. Birth weight and skin thickness were other important factors affecting cold resistance and part of the variation between breeds was associated with these effects. Remaining breed effects may be attributable to differences in metabolic rate capability. This possibility will be examined in a later paper. Despite the considerable range of birthcoat types available among the breeds used, cold resistance was not overall significantly affected by coat depth. On the other hand, within each of two groups of Blackfaces and Cheviots, cold resistance was higher among lambs with a greater weight of coat per unit area of skin. Between breeds the situation was different, the Blackfaces having lower cold resistance than the Cheviots despite a heavier weight of coat. Presumably, coat insulation affected cold resistance by trapping air between the water and skin surface, or by preserving a warmed layer of water next to the skin, during the early stages of cooling. The effectiveness of this type of insulation was apparently reflected more accurately by coat weight than by coat depth. However, other components affecting cold resistance, at least between Blackfaces and Cheviots, compensated for the effect of coat weight sufficiently to make the Cheviots more resistant.

The relationship between skinfold thickness and cold resistance may have been due to an association between skin thickness and nutritional status, or due to a direct effect of skin insulation perhaps associated with variation in skin histology, for example in subcutaneous fat deposition. Alexander (1978) found that Merino lambs had virtually no subcutaneous fat. Our own limited data suggest that the same may be true of at least some British breeds.

The effect of birth weight on cold resistance was expected since large lambs would be at an advantage with respect to heat loss because of their smaller surface area relative to mass. Moreover, within breeds, higher birth weights may be associated with better nutritional status and so greater energy reserves.

The three hill breeds were the most cold resistant and also showed the highest weight-specific cold resistance. The lowland breeds,

except for the Oxford, showed poor weight-specific cold resistance. Since one of the objectives of this experiment was to compare the cold resistance of feral and hill breeds on the one hand, and lowland breeds on the other, it may be legitimate to group them accordingly. Analysis of variance then shows a significant difference in mean cold resistance between the lowland breeds and the others ($P<0{\cdot}001$).

The procedure for re-warming lambs, involving forced warm air convection, while successful in producing fast recovery from hypothermia, was probably not optimal for revealing differences between lambs in recuperative ability. Nevertheless, the differences between breeds in mean unadjustified rate of recovery, although small, were significant, with the feral and hill breeds performing relatively well. The factors affecting rate of recovery were not clearly identified but the coats of the two feral breeds, which re-warmed quickly, appeared particularly capable of shedding or repelling water.

These results extend the findings of Slee *et al.* (1980) and show that a water immersion test allows some of the factors influencing resistance to hypothermia in newborn lambs to be distinguished. In terms of speed and simplicity in operation and high repeatability the waterbath seems more suitable as a tool for genetic selection than others which have been tried (Slee, 1978; Slee, Griffiths, Samson and Wilson, 1979). The main disadvantage is that differences in coat insulation, which probably affect cold resistance in the field (Purser and Karam, 1967), may not be fully effective in water. However, the relationship between heat loss and coat type could be separately evaluated by other techniques (Slee *et al.*, 1979). Such information could be used to define the desirable birthcoat (in terms of depth, density, *etc.*) and, with cold resistance data, could then be incorporated into a selection index.

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